The ENGLISH ELECTRIC JOURNAL

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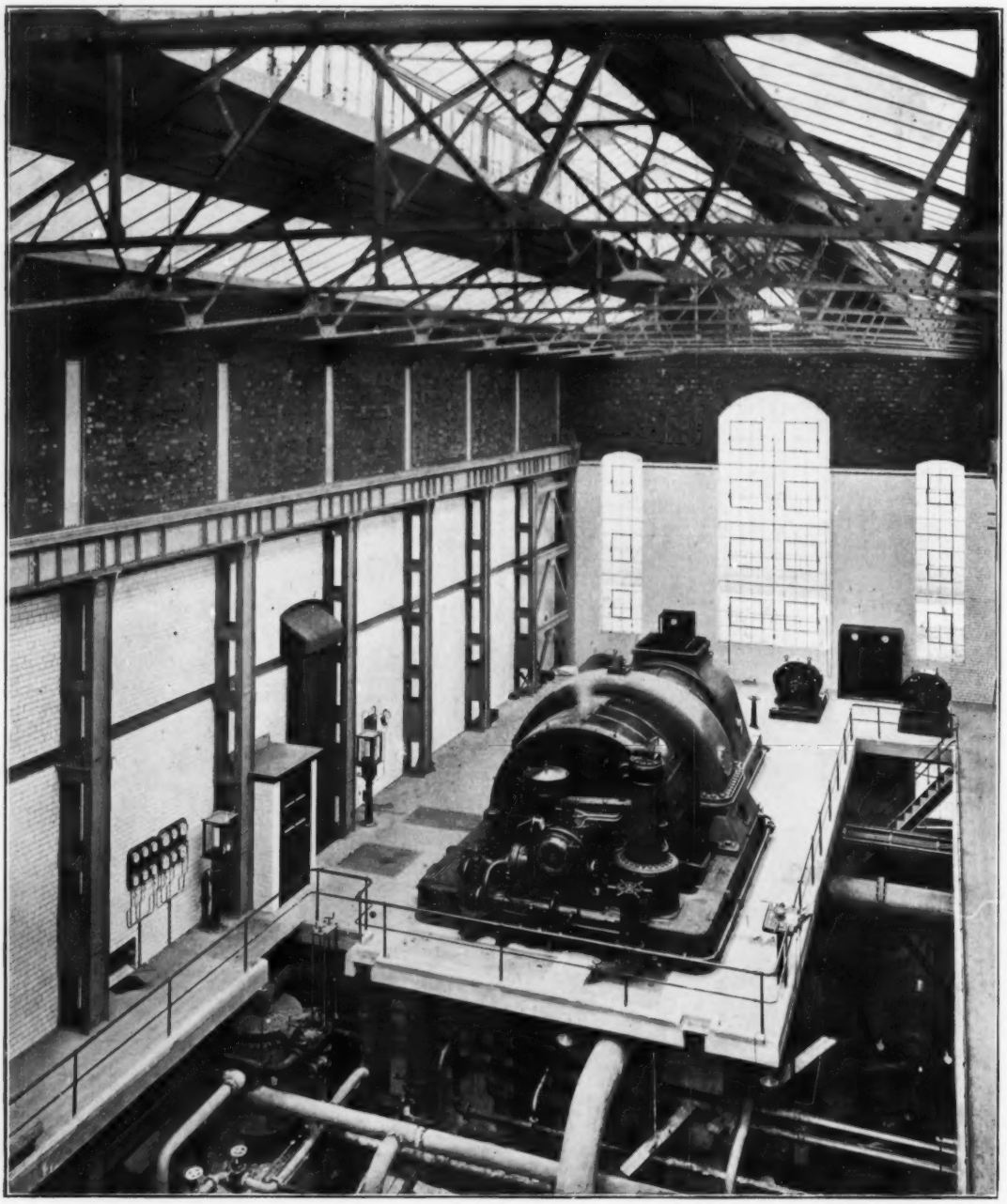

BLACKBURN (EAST) POWER STATION. ENGINE ROOM SHOWING ONE OF THE 10,000 K.W. TURBO-ALTERNATORS.

The English Electric Journal

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EDITORIAL.

All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, QUEEN'S HOUSE, KINGSWAY, LONDON, W.C.2.

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Power Supply and Railway Electrification.

We give prominence in this number of the Journal to articles on a large modern power station and on the English Electric Camshaft Control for heavy traction work. The two subjects are more intimately related than at first sight appears. The scientific organization of electricity supply and the application of electric power to railway transport are at the moment perhaps the most fruitful fields of development in the use of heavy electrical machinery. Moreover, they must proceed in step. Without an efficient and economical supply system the enormous and indisputable advantages of electric railway working cannot come into full operation.

The Power Station at Blackburn, of which we print a full description, is an example of what is being done for the improvement of electricity supply. The station is so situated as to meet

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the needs of a wide industrial area and as those needs grow it can be extended. It is built to ensure efficient and reliable working, and that aim is attained by the attention paid to every detail of the plant and to the fitting of each section into one consistent design. Every possible use has been made of automatic machinery in replacement of hand labour.

In the traction apparatus illustrated in the articles on the Camshaft Control and the New Zealand Railway electrification, the dominant aim is again efficiency and reliability. At the present time there are in course of manufacture at the Preston Works of the English Electric Company, and all embodying the system of control here described, complete main line electric locomotives for the Midland Railway of New Zealand and the Imperial Government Railways of Japan, electrical equipments of locomotives for the Midi Railway of France, and multiple unit equipments for the Nagoya Electric Railway Company in Japan, the Cataluna Railways in Spain and others. Some of these contracts have already been referred to in this Journal, and at a later date we shall have occasion to describe them in more detail.

The rapidity of the extension both of power station work and railway electrification depends now primarily on the restoration of confidence and stability in international economic relations. That, we are convinced, is the only cure for the unemployment which is at once a symptom and a cause of stagnation. The problem is essentially a political problem. How long the world will have to wait for its solution is still obscure. But there are in the present situation reassuring features. We can trace in this country and in many others the steady growth of a popular conviction that without peace in the fullest sense and sound finance and a spirit of co-operation, the future of Europe must be compromised. It makes no difference that this feeling springs from economic necessity. The important fact is that it exists, for in its absence Governments could hardly hope to carry through a sound economic policy.

Another factor of special interest to British industry is that every week brings nearer the restoration of a world price level. The internal financial policy which has made it possible for German manufacturers, in particular, to undersell competition is beginning to stultify itself. A continuous rise has taken place in costs and in prices of German products. Simultaneously, sacrifices both by employers and workers in this country have narrowed the gap still further.

The need of industry at the present time is closer co-operation for a common purpose. There are many signs that this is now widely recognised. Certainly the old misleading grouping of industry into Capital and Labour is dead, and on all sides we find a spirit more in accordance with the facts, which are that the prosperity of employers and workers and the nation as a whole are bound up together.

The Blackburn (East) Power Station.

By L. C. Kemp, B.Sc.(Eng.), A.M.Inst.C.E.

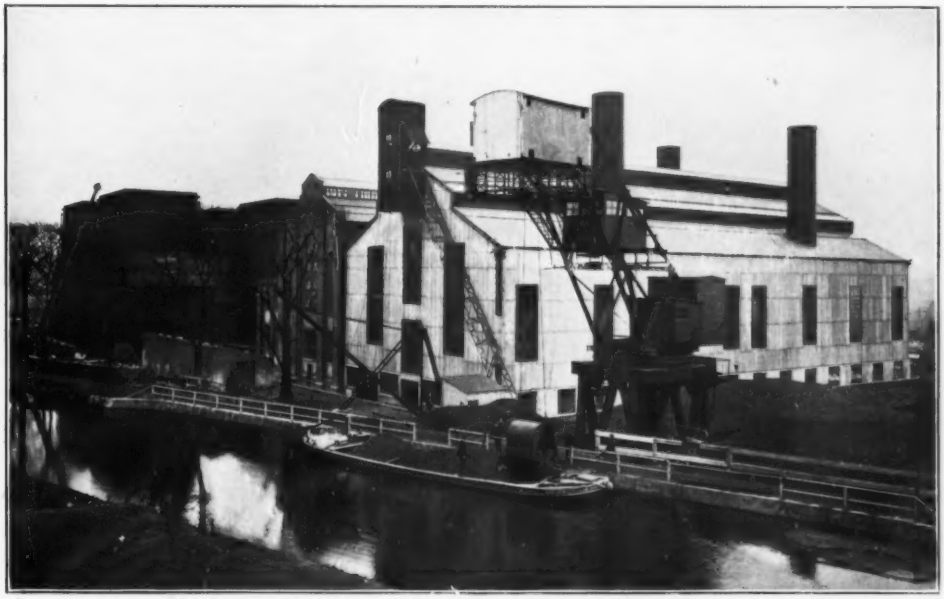


Fig. 1. General View of Station looking across the Canal.

The progress which is being made in the national development of large electrical generating stations has been strikingly brought to mind by the recent opening and successful operation of the new Power Station of the Corporation of Blackburn.

In pre-war days the necessity for expanding the electricity supply of this densely populated industrial district was well established and plans for a new 10,000 K.W. station were prepared and sanctioned, but, as in so many cases, a halt was called by the more pressing exigencies of munitions supply. After the Armistice, however, no time was lost and early in 1919 the position was reviewed afresh with the result that a station of at least double the original capacity was found to be necessary in order to cope adequately with the increasing demand for electricity which had been brought about as an outcome of war experience and the post-war needs for economy and efficiency.

The Borough Engineer, Mr. P. P. Wheelwright, M.I.E.E., revised his plans to cover a station containing two 10,000 K.W. units and this scheme was approved by the Corporation Electricity Committee and subsequently by the Electricity Commissioners. The station thus becomes the first of the large power stations to be erected under the provisions of the Electricity Act and is, moreover, one of the first examples in this country of a complex undertaking of that character being carried out under a comprehensive contract placed with one firm.

FIG. 2. STARTING THE RAFT, JANUARY 14TH, 1920.

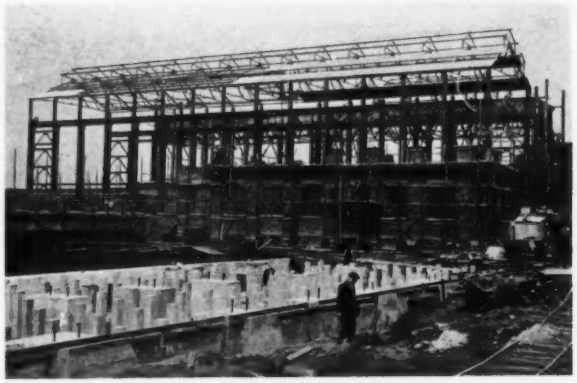


FIG. 3. VIEW FROM EAST, SHOWING COOLING TOWER FOUNDATIONS, JULY 31ST, 1920.

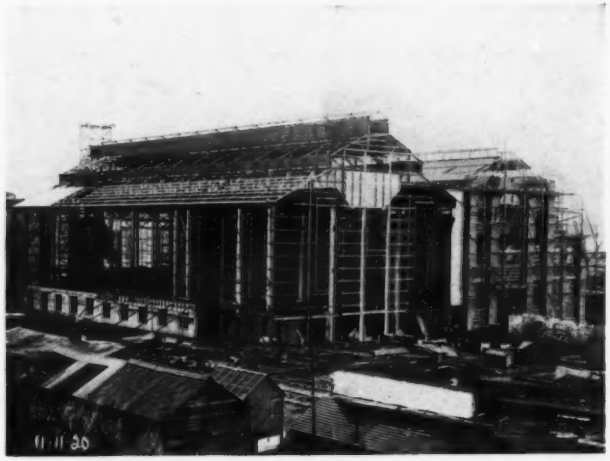


FIG. 4. BOILER HOUSE FROM WEST, NOVEMBER 11TH, 1920.

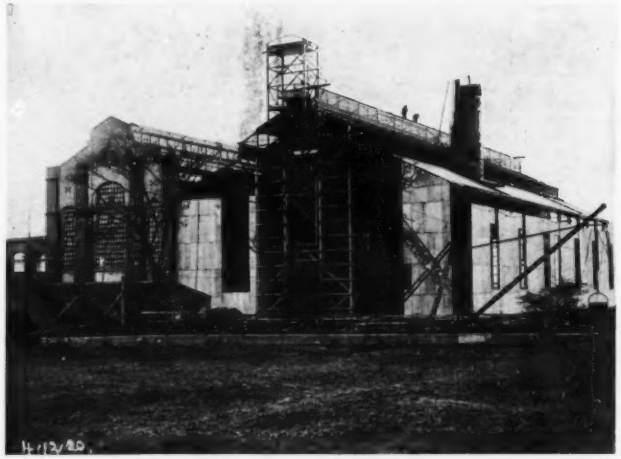


FIG. 5. VIEW FROM NORTH, DECEMBER 4TH, 1920.

The tender of The English Electric Company was accepted by the Corporation in August, 1919, and covered not only the provision of all the necessary plant, but also the foundations and structures themselves; the first sod was turned immediately afterwards and the laborious and intricate foundations had already been completed when the foundation stone was laid in the following May. The progress thenceforward was extremely rapid, as will be seen from the illustrations (Figs. 2 to 5).

The whole of the construction work was carried out on behalf of the main contractors by the Consolidated Construction Company, a company formed in 1919 to amalgamate the Dick, Kerr and J. G. White contracting departments. In this work the Consolidated Construction Company were greatly assisted, as were The English Electric Company throughout, by the precision with which Mr. Wheelwright made his requirements known.

The foundation stone was duly laid on May 13th, 1920, and after a lapse of less than eighteen months the first 10,000 K.W. turbo-alternator was started up by Lord Derby at the opening ceremony on October 21st last.

Particulars of Site and Foundation Difficulties.

The power station is situated at Higher Whitebirk, some three miles from the centre of the town and under the jurisdiction of the Rishton Urban District Council. It is adjacent to the Leeds and Liverpool Canal and to the Lancashire and Yorkshire Railway, so that alternative means are to hand for the delivery of coal or material.

An ample supply of make-up water for the cooling towers is available from the canal or from an artesian well which has been sunk to a depth of 170 ft. for this purpose. Also, as will be shown later, full advantage has been taken of the cooling surface of the canal to assist the cooling towers in obtaining the lowest possible inlet temperature for the circulating water.

The site, although so favourable in its facilities for economic coal handling and water supply, presented a special problem in regard to the choice of foundations for the large weights to be carried. The ground at this point is composed of a surface layer of soft peat about 5 ft. deep resting on a wet subsoil of silted clay. This insecure subsoil extends a considerable depth below the surface, making the piling of the foundations, on the whole, inadvisable.

It was therefore decided to carry the complete station on a reinforced concrete raft resting on the clay and so designed as to distribute the total weight over a large bearing area.

The raft, which supports a total load of 17,500 tons and covers an area of 3,800 square yards, consists of a series of concrete beams, approximately 2 ft. by 6 ft. deep in section, running both longitudinally and laterally, tied together by an adequate surface layer of concrete. The main beams are spaced about 12 ft. apart and are reinforced throughout on the Hennebique system, the amount of reinforcement introduced varying with the stresses in the raft and being specially concentrated beneath the turbo-alternators, boilers and chimneys where the maximum loads occur. The average bearing pressure on the clay subsoil amounts to 11·5 cwt. per square ft., a value which has been shown by experiment at site to provide a suitable factor of safety.

The system of drainage had to be considered with particular care, since the level of the power station basement is some 4 ft. below the normal canal water level, and also because the ground in the locality is extremely flat and waterlogged. Earthenware pipes have, therefore, been laid on the surface of the clay round the raft to provide for the effective drainage of the peaty surface, while cast-iron pipes have been arranged in the body of the raft for carrying away any water entering the basement, and to deal with general drainage from the machinery.

The Buildings.

The buildings are essentially steel structures, brick panelling being used to form the walls for the engine room, switch house and offices, and corrugated asbestos sheeting for the boiler house. In each case slate and glass have been used for roofing.

It may truly be said that this power station has one of the best naturally lighted engine rooms in the country. One half the total surface of the roof is glazed, and with the large windows in each end wall and the white tiling throughout, the light approaches from every angle and almost perfect illumination is obtained. As will be seen from the Frontispiece the engine-room floor does not extend over the whole area, ample spaces being left between the two generating sets and over the auxiliary plant. The light is thus able to penetrate freely into the basement and it is never necessary to use artificial illumination whilst daylight lasts.

The Coal and Ash-Handling Plant.

In the design of the coal-handling plant care has been taken to ensure that the coal is subjected to a minimum amount of handling in its delivery to the boiler-house bunkers or to storage.

The arrangement of the railway sidings and storage space relative to the power station and the canal will be seen from the general plan (facing page 26). A special wide-gauge track carrying a 20-ton Mitchell travelling crane runs between the storage dumps to a point adjacent both to the canal and to the underground receiving hopper of the skip hoist which feeds the boiler-house bunkers. The crane is thus able to command the whole area reserved for coal storage and to deal with coal arriving either in trucks or by barges.

In the former case a special attachment is fitted to the crane and the full coal waggons are lifted bodily and emptied either into the underground hopper or to storage as may be required. This operation is illustrated in Fig. 6.

Fig. 6. The 20-ton Travelling Crane Emptying a Waggon.

A feature of particular interest is that the hoisting platform of the crane is supported on knife edges, and an automatic weighing and registering device incorporated into the design by which the weight of each lift may be taken by the operator and an accurate record kept of the total amount of coal handled. First the waggon is weighed full, and then again when empty before being placed back upon the track, so that the nett weight of coal is ascertained.

A 14-ton English Electric battery locomotive is used for working the waggons in the sidings and bringing them beneath the crane. It has a rated tractive effort of 3,440 lbs. and a maximum tractive effort of 4,850 lbs. and is able to deal on the level with trains weighing 330 tons at a speed of 7 miles an hour. On a gradient of 1 per cent. it is able to haul 120 tons. The locomotive, which is illustrated in Fig. 7, is 20 feet long with a 6-ft. wheel base, and is equipped with two D.K. ventilated traction motors operated by a series-parallel controller.

FIG. 7. BATTERY LOCOMOTIVE SHUNTING WAGGONS.

For dealing with coal delivered by barge or for reclaiming from store, a one ton grab is fitted to the crane as in Fig. 1, and the coal weighed in transit as before.

It is to be noted that the coal is handled only once in its passage to storage or to the skip hoist, and that with the avoidance of the usual

FIG. 8. ASH REMOVAL IN BOILER HOUSE BASEMENT.

elevators and conveyors much mechanical wear and tear has been eliminated, with a resultant gain in economical working.

A fixed radius crane is also provided near the canal for handling comparatively small loads and to act as a standby in the event of the 20-ton crane being temporarily out of commission.

The delivery of the coal from the underground hopper to the coal bunkers is entirely automatic, one ton of coal being fed through a rotary feeder into the skip at each operation before the skip is elevated. The operations are counted so that a record of the total weight of coal entering the bunkers is obtained.

A Mitchell belt conveyor running the full length of the boiler-house roof, receives the coal from the skip hoist and discharges it into the overhead bunkers, even distribution being obtained by a hand-controlled device, which automatically diverts the coal from the belt at any particular point in the bunkers where it is required.

For the removal of the ashes from the boiler house and their disposal on the waste ground in the vicinity an exceedingly simple and efficient method has been adopted. A special ash waggon, designed to run on a narrow-gauge track, is brought beneath the ferro-concrete ash hoppers in the boiler-house basement by a 2½-ton English Electric battery locomotive and there filled with ashes. This operation is illustrated in Fig. 8, which shows also the head-room in the basement and the method of lifting the ash doors.

The waggon is then pushed by the same locomotive along the track outside the building to an ash-distributing plant where the ashes are emptied through sliding doors in the bottom of the waggon on to a moving belt and distributed evenly over the surrounding ground. The arm of the distributor extends over a large area and the entire plant is carried on a wide-gauge track of light pattern so that, as the ground is filled, the track may be readily laid over the ashes and the distribution carried on from the higher level. Only one man is required for the

operation of the electric locomotive and distributing plant.

The amount of ground which is available on the present site for the disposal of ashes is considerable, and it is anticipated that it will be many years before any alternative dumping ground will need to be considered.

The Boiler-House Equipment.

The boiler house, of which a general view is shown in Fig. 9, will contain, when completed, seven Babcock & Wilcox Cross Type Marine boiler units, each having a steaming capacity of 50,000 lbs. per hour as a normal output. Five or possibly six of these boilers will be placed in commission when the station is delivering its full output of 20,000 K.W., thus leaving one complete boiler, plus a margin of capacity in a second, to cover standby requirements. There are four main chimney stacks, constructed in steel and self-supporting, each being designed to deal with the flue gases from two boiler units.

Steam is generated at 210 lbs. per sq. in. working pressure, superheated to a total temperature of 600 degs. Fahr., and is collected in a common wrought-steel header running the whole length of the boiler house, increasing in size from each end to the middle, where branches are fitted for the main steam supply to the turbo-alternators.

Each boiler unit is fitted with integral

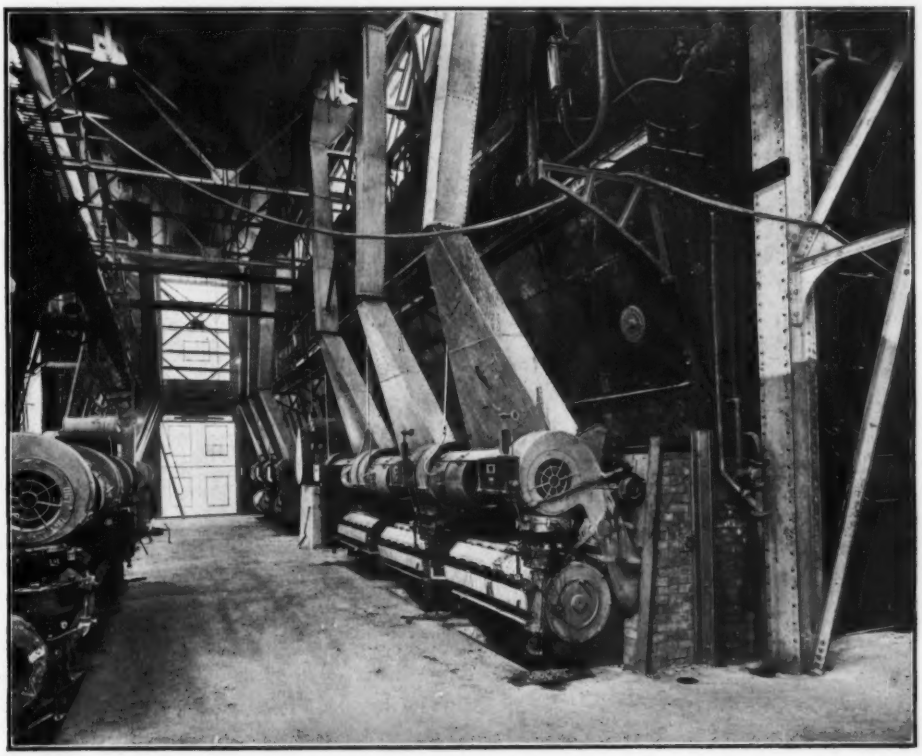


Fig. 9. View in Boiler House.

superheaters, superposed cast-iron pipe economizers, and three mechanical stokers of the well-known Underfeed travelling grate type, operated on the balanced draught system. The combined heating surface of each boiler and economizer amounts to 12,436 sq. ft. and the area of the three grates to 290 sq. ft.

The arrangement of the stokers and coal chutes will be clearly seen from Fig. 9. The air for each grate is supplied by two forced-draught fans mounted on a common shaft in front of the boiler and driven by an English Electric totally-enclosed motor.

Induced-draught fans are arranged at the base of each chimney, and draw the products of combustion down the chimney from the outlet on the economizer. English Electric pipe-ventilated motors each of 95 H.P. are used for driving these.

The gases, after passing through the fans, are discharged upwards through a separate portion of the chimney, a vertical dividing plate being fixed internally, separating the chimney into two portions at this section. The arrangement of one of the fans, its motor and control gear, is shown in Fig. 10.

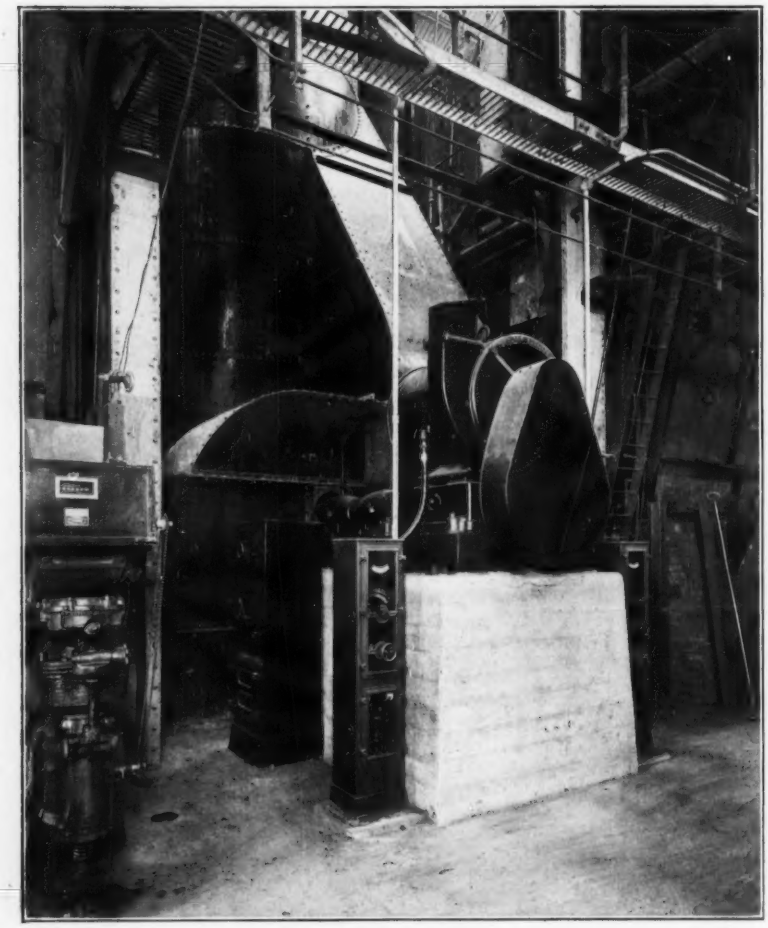


FIG. 10. BASE OF CHIMNEY WITH INDUCED-DRAUGHT FAN.

The balanced draught system has been adopted for the special purpose of maintaining a high efficiency of combustion with fuels of the poorer quality and varying heat value. This system requires less total power for the operation of the fans than a totally induced-draught system, and it is claimed that fewer fan troubles are experienced, whilst thermal losses due to the leakage of air through the

brickwork settings are practically eliminated.

The coal is measured as it passes from the chutes on to the travelling grates by Lea coal meters attached to each stoker. The meters are arranged to record the number of cubic feet of coal or slack passing to the furnaces, and by multiplying by the weight per cubic foot of the particular fuel used, a close approximation of the total weight burned in each boiler is obtained. Tests have shown these meters to be correct under normal conditions to within 1 to 3 per cent.

The boiler-house bunkers have a total capacity of 1,200 tons, which is approximately equivalent to two days' supply with the station on the full load of 20,000 K.W. continuously, or about a week with the station operating under normal conditions of load factor.

The condensate from the turbines is delivered by turbine-driven feed pumps direct to the inlets of the economizers, where it is heated by the gases of combustion.

For controlling the supply of feed water to the boilers, Cope's automatic regulators are used; they are fitted to each boiler unit and permit a continuous feed at a rate in proportion to the demand on the particular unit. Their operation depends on the expansion and contraction of a heavy metallic tube mounted on a base and connected by a lever and strut to a control valve in the feed line. Briefly, the regulator consists of a heavy inclined tube or thermostat situated at the level of the top drum and arranged so that the lower half is filled with water and the upper half with steam. As the load increases and the water level falls, the proportion of the tube filled with steam is increased and the added expansion of the tube actuates the lever mechanism of the feed control valve and causes an increased rate of feed to the boiler. For a decrease in the load, the converse action takes place.

The continuity of the feed obtained by this means is of great value in this particular installation, as will be appreciated in considering ater the closed feed system by which the turbine condensate is returned to the boilers.

The method adopted for cleaning the soot from the tubes and heating surfaces of the boilers is of special interest, as it is believed that this station is the first in the country to be equipped throughout with a device of this kind, which can be operated whilst the boiler plant is in service. The apparatus is known as the Diamond Soot Blower and consists of a series of rotating steam pipes, disposed at various points within the furnace, by which steam issuing from nozzles at high velocity may be directed on to the tubes and heating surfaces.

When the steam is released among the tubes at a velocity in the neighbourhood of 2,700 ft. per second a perfect whirlwind of currents is created, reaching all the nooks and crannies of the boiler and thoroughly removing particles of soot and fine ash deposit.

The operation requires only from 20 to 50 seconds and is performed two or three times a day whilst the boiler is under load, using a greatly decreased amount of steam and labour as compared with the hand hose or any other system of blowing. In any case, the expenditure of steam is more than compensated by the increased efficiency obtained in the working of the boiler, and the system has the advantage that the cleaning is effected without admitting air, with its consequent cooling effects, to the inside of the boiler setting.

The Engine-Room Equipment.

The main plant consists of two 10,000 K.W. 1,500 R.P.M. English Electric turbo-alternator units. They are designed to operate with steam at a pressure of 200 lbs. per square inch at the turbine stop valve, 200° F., superheat, and a vacuum varying between 28 ins. and 29·2 ins., depending upon the season of the year and the degree of cooling effected by the towers, and to generate three-phase, fifty-cycle current at 6,600 volts.

The turbines are of the latest English Electric impulse type, each having one compound

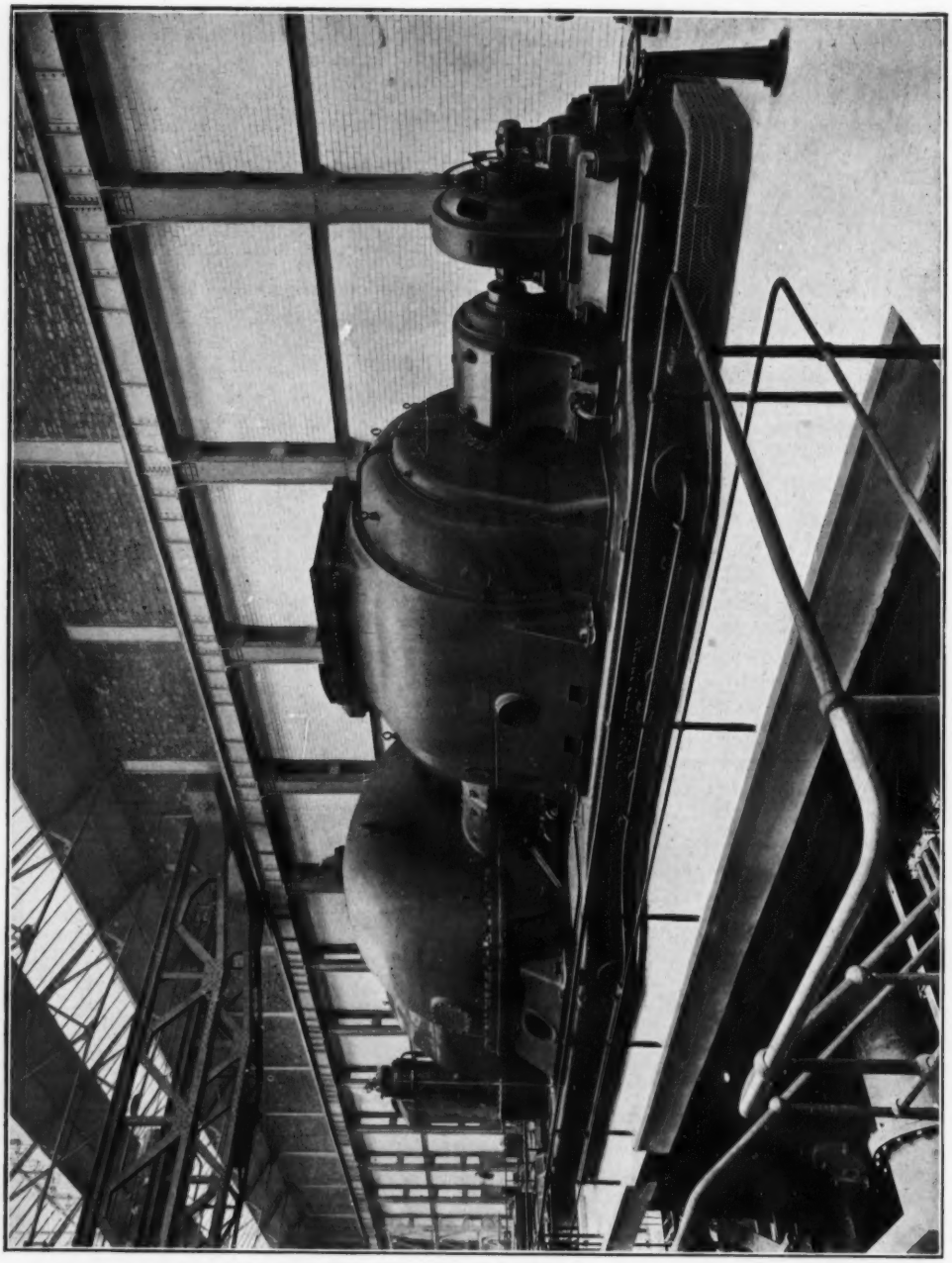


FIG. 11. ONE OF THE 10,000-K.W., 1,500-R.P.M. TURBO-ALTERNATORS.

velocity stage and nine single impulse stages. They are provided with partial load governing by which high efficiency in steam consumption is maintained at partial loads and overloads, as well as at the normal full-load rating of the machines. The high-pressure steam belt, which is constructed in cast steel, is divided into three sections by means of auxiliary-nozzle control valves, which are directly actuated from the oil relay cylinder of the governor gear. The governor gear is arranged so that the first portion of the travel of the oil relay system affects only the supply of steam to the first section of nozzles, but any movement beyond this is utilized to open consecutively the full load and overload nozzles. Michell thrust blocks and sealing glands of the carbon-ring type are embodied in the design of these machines.

The alternators, which are of standard English Electric construction, are designed for a normal full load of 12,500 K.V.A. at ·8 power factor when generating three-phase current at 6,600 volts, 50 cycles and are further capable of carrying 25 per cent. overload (15,625 K.V.A.) for two hours.

Both the stator and rotor windings are insulated with mica and substantially braced to prevent any movement in the coils either under the influence of short circuits or of centrifugal force. On the rotors, which are of the ventilated type, fans are provided which draw the cooling air from the filters, the warm air being exhausted through adjustable air dampers situated on the top of the stator frames. The exciter armatures are carried on their own pedestal type bearings and driven through

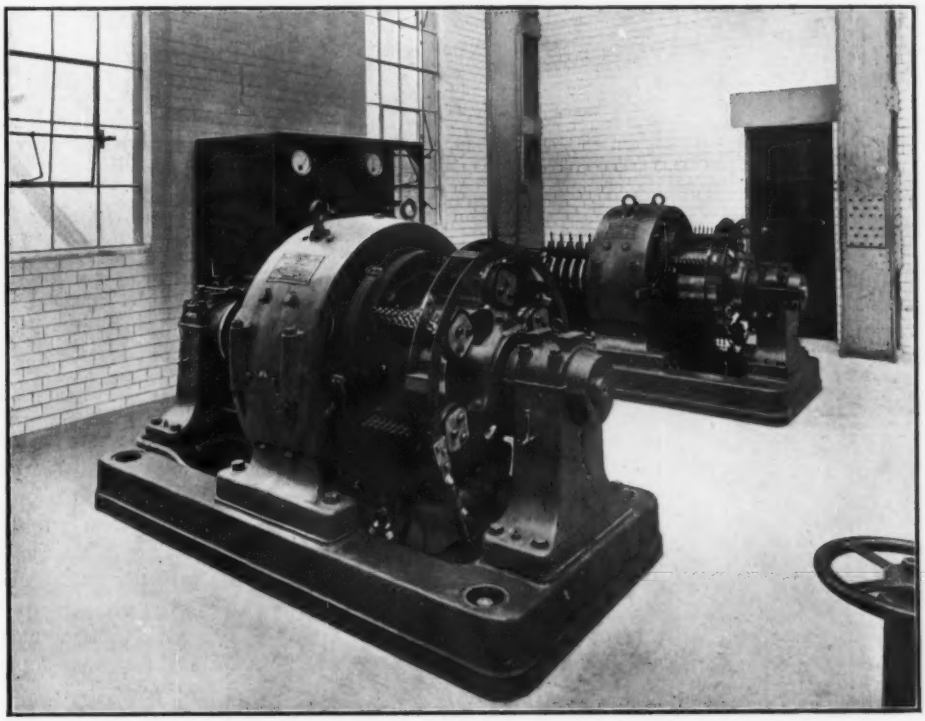


FIG. 12. 320-K.W. ROTARY CONVERTERS.

flexible couplings from the main shafts. The general appearance of the turbo-alternator and exciter will be seen from Fig. 11.

The cooling air is taken from Hart air washers situated in the engine-room basement.

Three 320-K.W. English Electric rotary converter equipments (Fig. 12 and Frontispiece) installed at the end of the engine room provide D.C. supply at 440 volts for the station auxiliaries. These machines are shunt wound and designed for self-starting by means of L.T. tappings on the A.C. side.

The steam from the turbines is condensed in Hick, Hargreaves surface condensers, each of which is designed to deal with 125,000 lbs. of exhaust steam per hour, and to maintain a vacuum of 28 ins. when the temperature of the cooling water is 80°F. A cooling surface of 19,000 sq. ft. has been provided in each condenser. Steam air-ejectors of the Hick-Breguet type are fitted, in which Delaporte's automatic air regulating valves are employed for giving stability of vacuum under varying conditions of working.

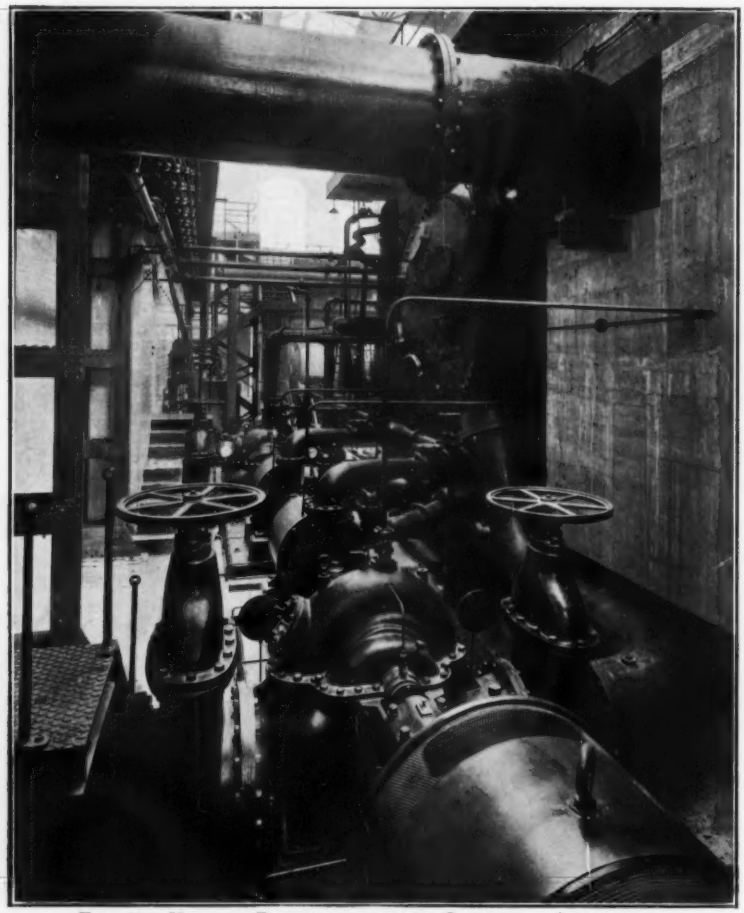


FIG. 13. VIEW IN BASEMENT SHOWING CONDENSER AUXILIARIES.

The condenser auxiliaries for each main unit are divided into two sets, the one motor-driven, and the other driven through gears from a steam turbine running at 5,000 r.p.m. This turbine is an English Electric machine of standard impulse design, with one compound velocity stage and three single impulse stages. These sets are illustrated in Fig. 13.

Each circulating pump is designed to deal with 60 per cent. of the total water required for the normal full load working, whilst each extraction pump is capable of dealing with the full quantity of condensate.

When the main units are developing 6,000 K.W. or less it is only necessary to bring one of the pumps into

action, and a saving in the total power consumed in the auxiliary plant is thus obtained. Further, the system provides a useful safeguard in the event of the possible failure of one of the pumps, and also carries with it the advantage that at least 60 per cent. of capacity in the auxiliary plant is dependent only upon the boiler house for its operation and is entirely free from the effect of electrical disturbances or limitations.

The condensate after passing through the extraction pumps enters a " closed feed system," the primary object of which is to provide the boilers with pure de-aerated feed water, and thus to improve the evaporating efficiency and reduce as far as possible the formation of scale on the tubes. The system, which is designed to operate automatically and continuously, has many features of interest.

Referring to the diagrammatic arrangement (Fig. 14) the condensate is withdrawn from the main condenser A in the usual manner by means of a centrifugal extraction pump B, by which it is discharged through non-return valve C, control valve D and Venturi meter E and then through a small heater F, in which it is heated by means of the steam issuing from the secondary jet G on the Hick-Breguet Ejectair. It then passes forward through a surplus valve H and control valve J into a main heater K, which is supplied with steam from the auxiliaries and evaporator, where it is heated up still further. After this it passes through valve L and thence direct through valve M in the feed pump suction to centrifugal feed pump N, by which it is finally discharged through valve O to the boilers.

The steam-driven auxiliaries in this case consist of the circulating and extraction pump turbines, feed pump turbines, secondary ejector and evaporator; all these, with the exception of the secondary ejector discharge steam into the main heater. The steam is led to the heater by means of the auxiliary exhaust main P, the supply being controlled by means of valve Q.

The drips from this heater are collected in a feed tank R and regulated by valve S, a bye-pass valve T being provided along with suitable piping to enable the heater to be cut out if required for repairs at any time.

The evaporator U is supplied with steam by means of an automatic valve V controlled by a ball float in feed tank R, which regulates the supply of steam to the heating coils as may be required to make up the level of water in the feed tank; the drips from these heater coils are taken to the body of the main heater and thence pass along with the main heater drips to the feed tank. The drips from the evaporator coils are controlled by valve W. Water is supplied to the evaporator from any suitable outside source, in this case the main storage tank, through valve X. In addition to the automatic valve V, an isolating valve V_1 is provided.

The make-up water from the feed tank R is delivered to the main condenser for de-aeration purposes, through an automatic make-up feed valve Z, and Venturi meter E.

The operation of this automatic feed valve is so arranged that when a fall in pressure takes place in the delivery pipe from pump B, as would be the case if the delivery of the feed pump was increased, this hydraulic pressure immediately acts on a piston in the automatic feed valve, in this way opening the valve and permitting an augmented supply of water to be passed along pipe A_1 into the condenser, where it would be thoroughly de-aerated before passing into the extraction pump suction by means of pipe B_1 and valve C_1. The pipe connecting the extraction pump delivery with the automatic make-up feed valve Z is indicated in the diagram by the letter D_1.

Should the rate of feed to the boilers be curtailed, in this way setting up an increased pressure in the delivery pipe from pump B the reverse action would take place, and the flow of make-up feed water through valve Z would be automatically reduced to correspond with the demand.

In the event of a supply of make-up water from the evaporator not being available, the level of water in the feed tank under normal full load, or any load exceeding this, would drop, in this way unsealing the end of pipe A_1 in the feed tank. To prevent this taking place and to ensure a supply of water in the feed tank under all conditions, a ball float E_1 is provided, controlling a supply of undistilled water from the main storage tank. This valve is also used should it be necessary for any reason to feed the boilers with undistilled aerated water for a prolonged period, valve F_1 being opened to allow of this method of working.

An overflow pipe G_1 is provided at a suitable level in the feed tank for clearing away any excessive accumulation of water, the overflow being made visible by discharging it into a tundish H_1.

Should the contingency arise in which the extraction pump B is discharging more water than is required by the boilers, the surplus-valve H would immediately open and deliver the excess water to the feed tank, this method of working proceeding automatically until the demand for boiler feed water became normal.

On light loads the amount of feed water passing through the main heater may not be sufficient to condense all the steam being delivered to it, in which case the pressure in the heater and auxiliary exhaust main will rise until the spring-loaded relief valve J_1 is lifted and the excess steam passes into the atmospheric exhaust pipe N_1 at a point beyond the atmospheric exhaust valve of the main turbine. If desired, this excess steam may be discharged into the main condenser, in this way conserving the condensate from this source for boiler feed purposes.

In connection with the operation of the small heater F, it will be noted that the whole of the air extracted by the Ejectair K_1 is discharged into it along with the steam from the secondary ejector, and as it is highly necessary that this air should be expelled from the system immediately, a suitable vent chamber L_1 is provided, to which is coupled a pipe M_1 connected direct to the main atmospheric exhaust pipe N_1.

From the above description it will be noted that in addition to providing a de-aerated and distilled supply of water to the boilers, the system takes advantage of every opportunity to conserve heat and so assists materially in securing a high overall thermal efficiency of the plant.

The Cooling Towers and Circulating Water System.

The circulating water for the condensers is drawn from the ferro-concrete ponds of four large Film cooling towers. These towers, which are built on the double tower system, as will be seen from the general views of the power station, embody a somewhat novel and interesting construction by which water passes along inclined laths, and the cooling depends upon film rather than splash as is usual in most types of towers.

The water is led into the tower some 26 ft. above the level of the pond and is distributed over the whole area of the tower by means of trough channels. Jets of water issuing from nozzles beneath the troughs are split up initially in cups arranged beneath the nozzles, and the drops of water fall on a number of inclined laths and flow down them. At the lower end of each lath is formed a V through which the water passes and falls on to the upper end of the next inclined lath, the process being repeated until the bottom is reached. The interiors of the towers are thus filled with series after series of these inclined laths along which films of water pass, and it is claimed that this construction, whilst presenting an immense cooling surface, allows a comparatively free passage for the air entering and passing through the towers, thus increasing the total air quantity and improving the cooling effect.

Make-up water for the cooling ponds to cover

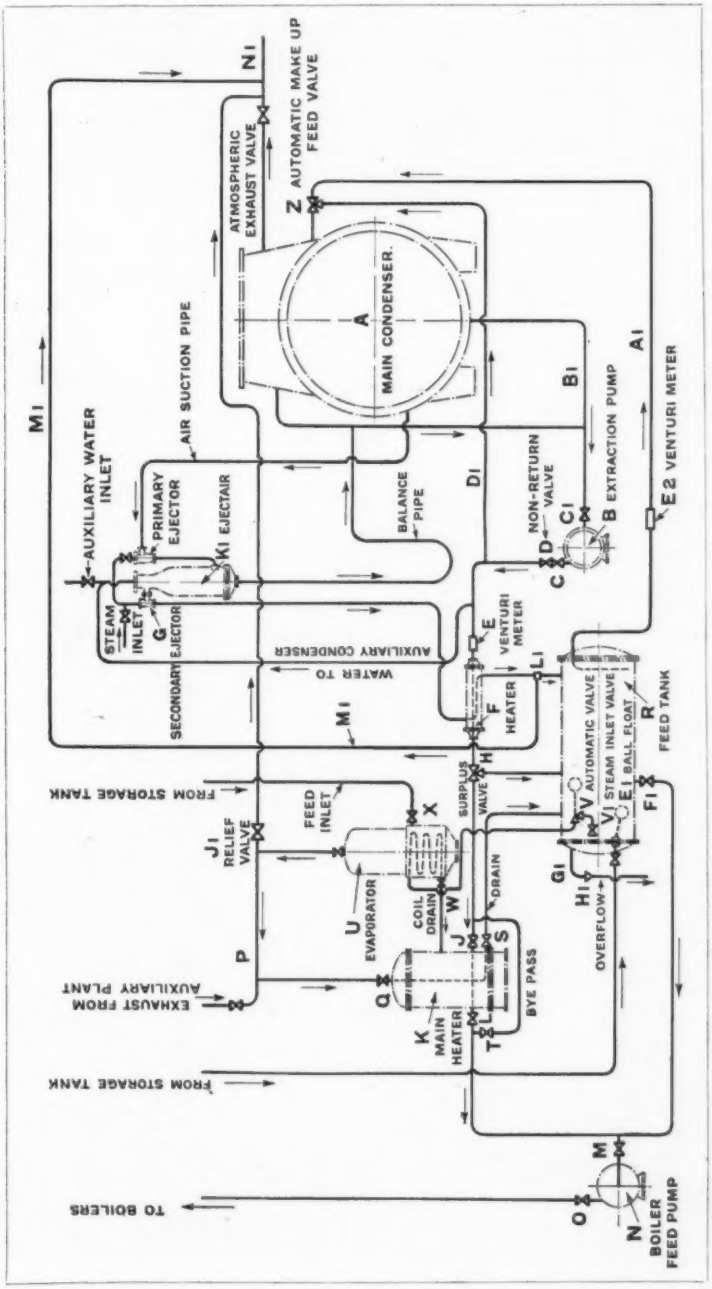


FIG. 14. DIAGRAM OF CLOSED FEED SYSTEM

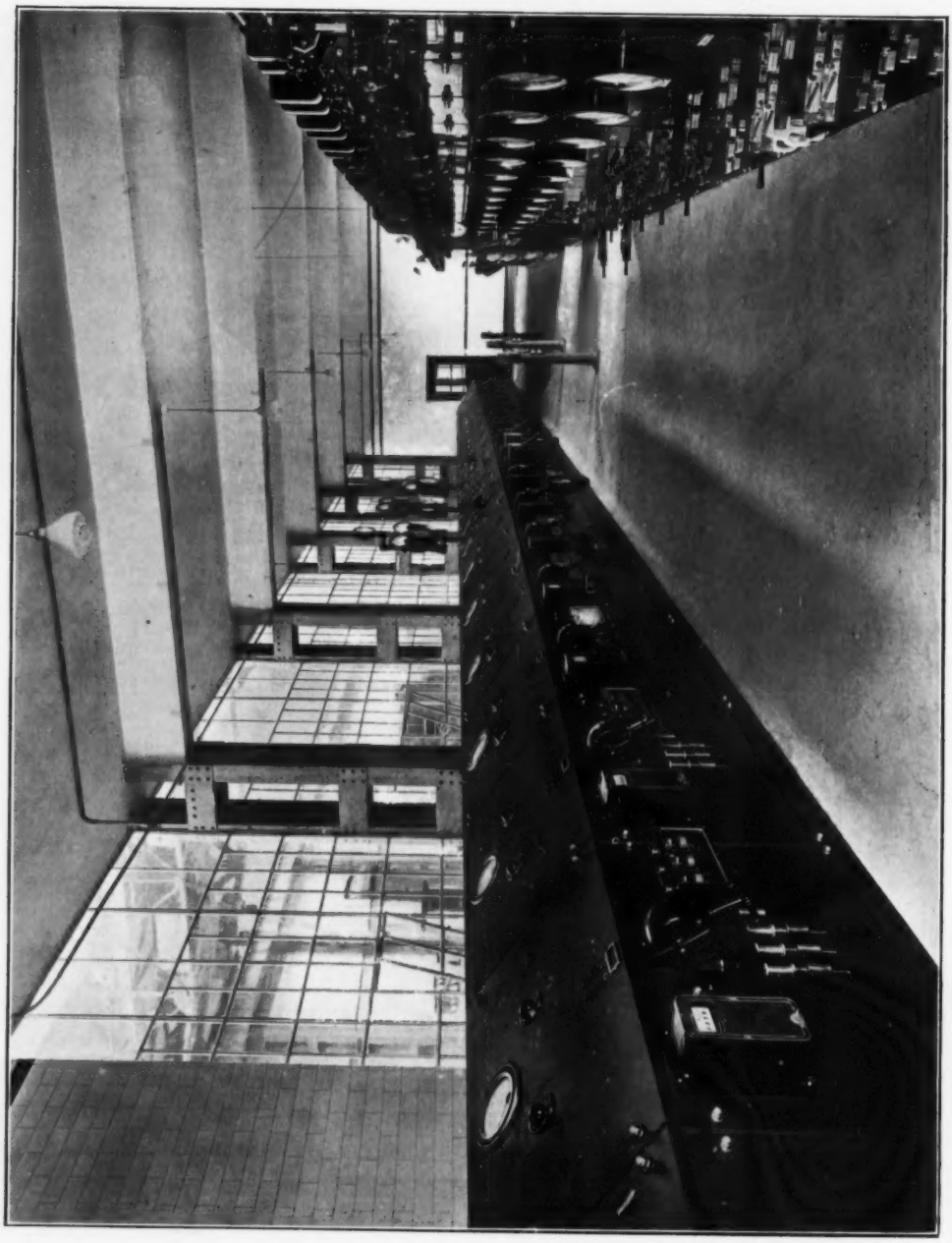


FIG. 15. SWITCHBOARD ROOM.

loss by evaporation from the towers is obtained either from the canal or from the artesian well already mentioned.

A water storage tank of 18,000 gallons capacity is provided for purposes of emergency water supply either to the cooling tower system or to any part of the power station where it may be required. The tank is supported on the roof of the annexe to the engine-room.

In all power stations such as this, where the overall efficiency of generation depends to an important extent on the results obtained from artificial cooling, great advantages may often be derived from a close examination of the site conditions with a view to utilizing any natural facilities which are likely to improve the effectiveness of the cooling system. In this case investigation showed that by utilizing the cooling properties of the canal in parallel with the towers the bottom temperature of the circulating water could be reduced in the winter months by some 5° to 7°F., resulting in a better vacuum at the condensers and a reduction of approximately 1·3 to 1·6 per cent. in the turbine steam consumption. It was further calculated that the maximum assistance could be obtained from the canal by using it to cool 40 per cent. of the circulating water of one set, the inlet and discharge openings to the canal being spaced about 150 yards apart.

The circulating water discharge pipes from each set are led direct to the towers and bye-pass branches are provided by which a proportion of the hot water may be carried forward to the canal, the loss of water in the cooling tower system being automatically corrected by a supply of cool canal water entering the ponds through large float valves.

Hand-controlled valves are provided by which the quantity of hot water bye-passed may be regulated, and Venturi meters are fitted on both the bye-pass discharge and intake for the purpose of recording the water in circulation at any time. The difference in the readings of these two meters also provides a record of the amount of water which has been taken from the canal for make-up purposes.

A further point of interest is that the pipework between the circulating pumps of the two sets and the towers has been interconnected, so that it is possible for either set to draw water from or discharge it to any one or more of the four towers.

The Switchgear and Transformers.

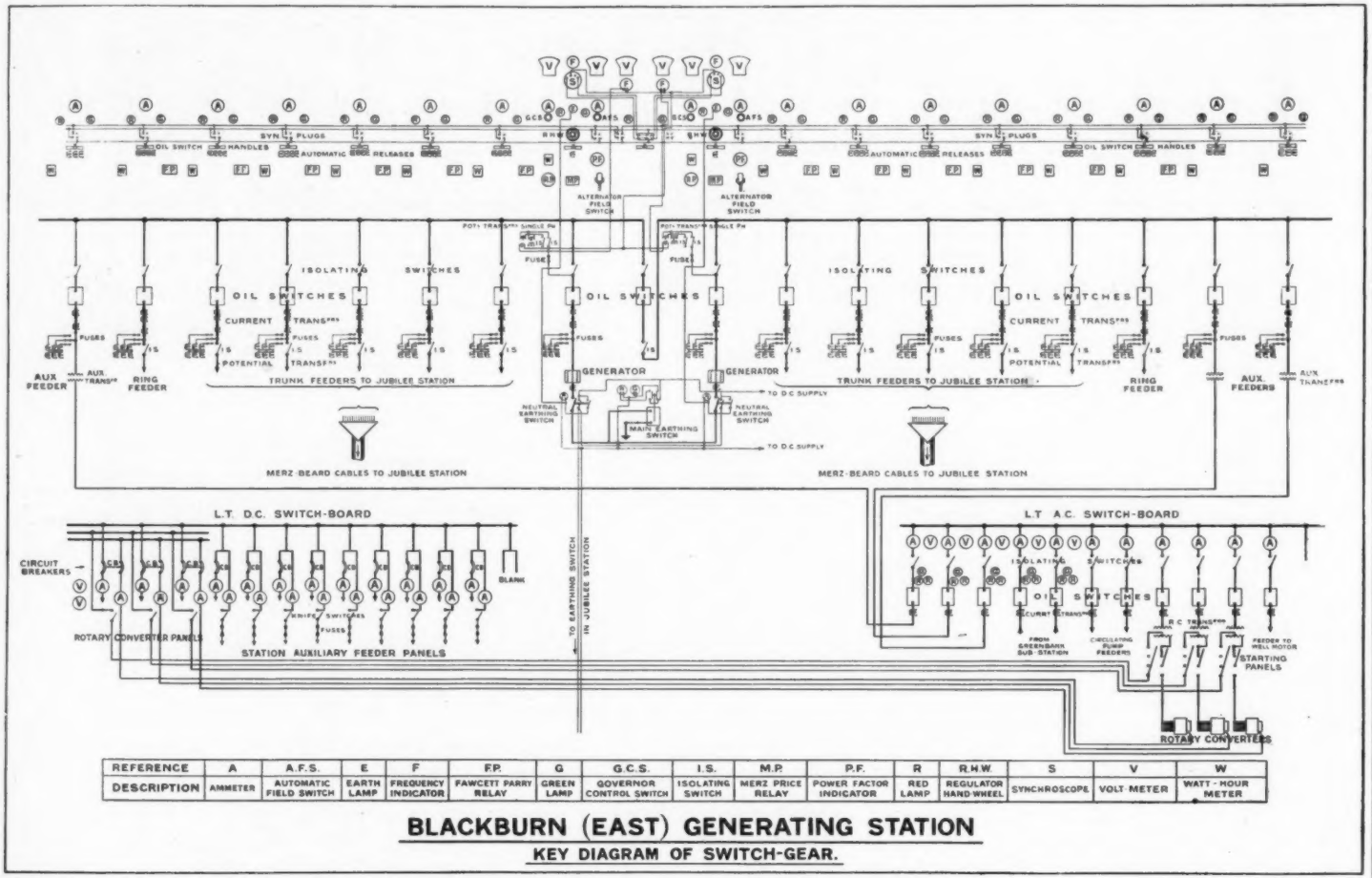
The station is equipped with English Electric switchgear, the control panels for the high-tension A.C., low-tension A.C. and D.C. circuits being arranged in an annexe to the engine-room.

The general scheme of connections, which provides for the parallel running of the plant with the Jubilee Street Station, will be seen from the key diagram, Fig. 16. The busbars are simple three-phase bars divided by a coupling equipment into two sections, one for each turbo-generator. These sections are connected to the Jubilee Station by a number of main trunk feeders and also to the transformers supplying power to the station auxiliaries.

The generator neutrals are connected to a common bar which can be earthed through an oil switch and resistance, an indicating device being introduced to show when the system is earthed at the Jubilee Station, in order to prevent the earth connection being made at more than one point.

For the supply of power to the station auxiliary plant, both alternating current at 400 volts and direct current at 440 volts are available, the latter being obtained through the rotary converter equipment. These converters are started up on the A.C. side by means of tappings on their static transformers, from which also a further tapping is taken direct to the D.C. board to provide the neutral of a three-wire system. The greater portion of the power for the auxiliary plant is taken from the D.C. board.

A special arrangement of signal lamps on the low-tension A.C. board has been devised in



REFERENCE	A	A.F.S.	E	F	F.P.	G	G.C.S.	I.S.	M.P.	P.F.	R	R.H.W.	S	V	W
DESCRIPTION	AMMETER	AUTOMATIC FIELD SWITCH	EARTH LAMP	FREQUENCY INDICATOR	FAWCETT PARRY RELAY	GREEN LAMP	GOVERNOR CONTROL SWITCH	ISOLATING SWITCH	MERZ PRICE RELAY	POWER FACTOR INDICATOR	RED LAMP	REGULATOR HAND WHEEL	SYNCHROSCOPE	VOLT METER	WATT-HOUR METER

BLACKBURN (EAST) GENERATING STATION

KEY DIAGRAM OF SWITCH-GEAR.

FIG. 16.

order to prevent the incoming feeders from existing town sub-stations being connected to a part of the system with which they are out of synchronism.

The operating room, Fig. 15, contains the main high-tension switchboard and the two low-tension boards.

The high-tension switchgear is controlled from a desk-type board carrying the oil switch operating handles, overload trips with time limits, protective relays, meters and automatic voltage regulators on the vertical panels, and the indicating instruments and lamps, synchronizing sockets and generator field rheostats on the inclined panels. Synchronizing instruments and voltmeters are provided in duplicate, and are mounted on brackets behind the three central panels of the desk board.

The low-tension switchboards are arranged facing the high-tension desk board, and are spaced well apart, the operator's desk and telephone being placed between them.

For communicating with the engine-room and boiler house, an electrically operated ship's telegraph apparatus has been installed, also the speed of the running machines may be controlled from the switchboard by means of governor control switches.

High-tension Apparatus. The high-tension apparatus is housed in stonework cells arranged immediately beneath the operating room. The arrangement of the cellwork and switches will be seen from Figs. 17 & 18. Phase barriers have been provided throughout, so that the containing chambers are thus rendered fireproof. The cells are double-sided in order to allow the oil switches and current transformers to be mounted in a central position on the one side, and the busbars and isolating switches on the other. This arrangement has the advantage of minimizing the possibility of gases or fumes reaching the busbars and their isolating switches.

The busbars themselves are arranged in stonework troughs, each bar in a separate compartment with openings or inspection doors wherever necessary. Throughout the whole of this

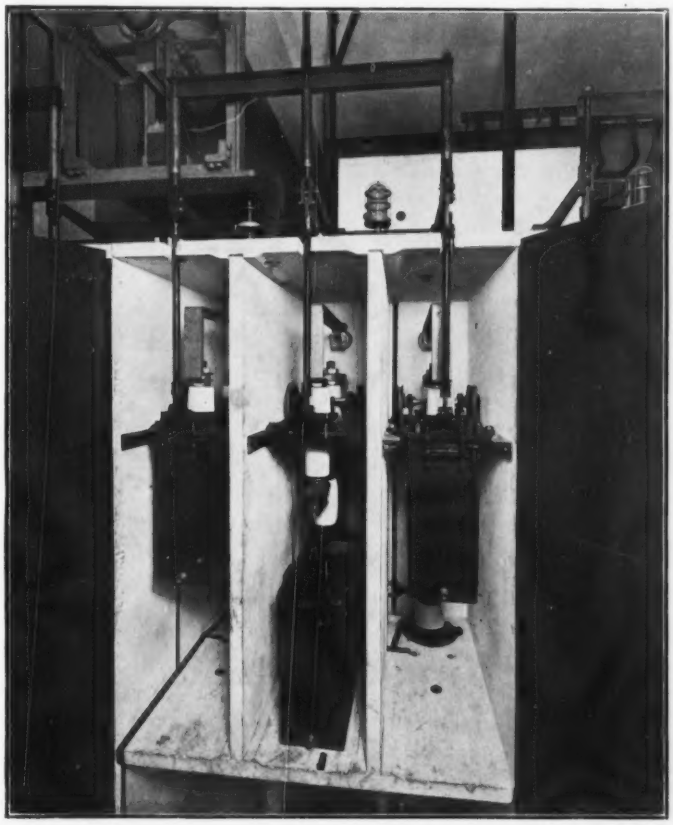


FIG. 17. HIGH-TENSION OIL SWITCH.

equipment particular attention has been paid to the accessibility of the insulators for purposes of cleaning or repair.

The oil switches are hand operated from their respective control panels, and special catches have been provided on the operating handles in order to give a definite synchronizing position in each case. The oil switch of an incoming machine can thus be partially closed until the contacts are only a short distance apart and held in this position mechanically. When the instruments indicate that the two sides of the switch are in synchronism, the remaining movement of the operating handle closes the switch finally, an action which is naturally far less arduous than would be required to close the switch from the full open position.

The oil switches are of the English Electric patented explosion-proof type in which each phase has three breaks in series arranged vertically in the middle of the tank. The design is such that air pockets within the tanks are entirely eliminated, so that the gases caused by the arc when breaking current cannot mix with air to form an explosive mixture inside the switch. The tanks are attached to the top plates by means of a spring suspension device, thereby relieving the switches of any excessive momentary internal pressure which might otherwise arise owing to the absence of an air cushion. Each of the larger oil switches has a tank-lowering gear operated from the front by means of a removable handle, as will be clearly seen from Fig. 17. For the smaller oil switches a portable tank-lowering device is employed.

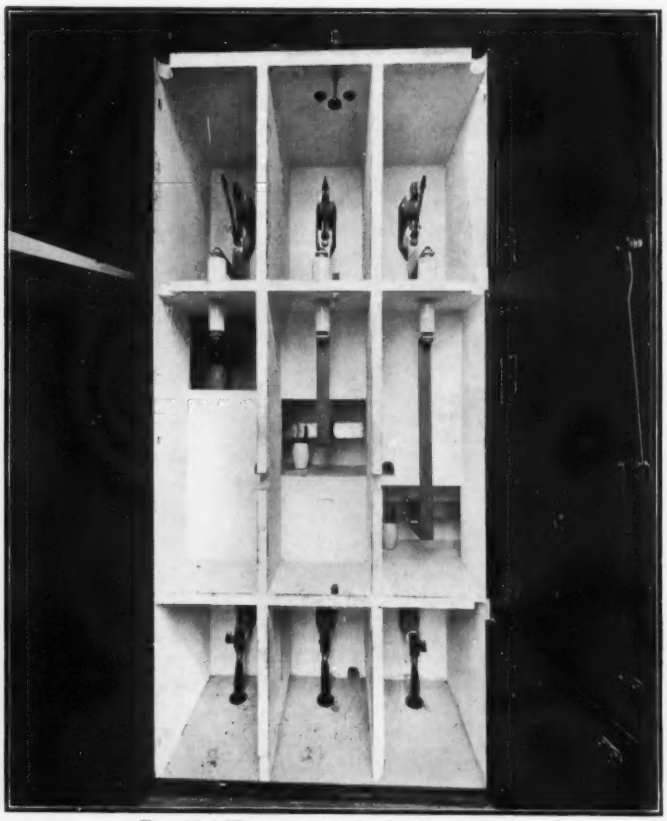


FIG. 18. HIGH-TENSION ISOLATING SWITCH.

The isolating switches, Fig. 18, are of standard pattern, provided with safety catches to prevent their being blown open by momentary heavy currents. Indicating lamps above each cell show whether the apparatus inside is alive or safe.

The whole of the high-tension apparatus is enclosed by sheet-iron doors, which are interlocked in such a manner that they cannot be opened unless the oil switches are in the "off" position ; moreover, the isolating switches cannot be opened whilst current is flowing—an important point, since many accidents have occurred in the past through the inadvertent or careles

operation of isolating switches in a circuit on load.

Protective Apparatus. In addition to the indicating lamps for the prevention of mistakes in switching, a number of devices have been employed to detect and isolate faults which might occur either in the machine or in the system outside the generating station.

The generators are protected by means of the well-known Merz-Price circulating current device, in which current transformers near the oil switch are balanced against current transformers on the opposite side of the alternator before forming the neutral point. In the event of a fault occurring in the alternator, this balance is disturbed and relays are brought into action which open the main oil switch. As an additional safeguard, an automatic field reversing switch has been provided, operating in conjunction with the balanced protective gear, so that should the latter open the main oil switch on an incipient fault in the generator, this automatic switch would immediately reduce the stator field to zero in the shortest possible time, thus preventing the machine from doing further damage to itself, and limiting the fault to comparatively small dimensions.

The feeders have been equipped with Beard-Hunter balanced protective gear having compensated pilot wires, a system devised to limit the effect of the capacity current in the pilot wire. In the earlier systems of protection on the same principle, this capacity current sometimes caused the oil switches of sound feeders to open on overload, especially in the case of feeders of considerable length. The Beard-Hunter system provides a pilot wire with a special compensating conductor, which is severed so that current cannot flow from end to end, but at the same time is so connected that the release and tripping coils are unaffected by a capacity current. This being the case, it is possible to use extremely sensitive relays in order to catch a fault on a feeder before it has assumed the proportions of a short circuit. These relays, which have been provided on the feeders and are of the Fawcett-Parry type, work satisfactorily with one-tenth of the energy required for the ordinary type of relay hitherto used, and are far less sensitive to external vibrations.

Auxiliary Switchgear. This is of standard English Electric low-tension type, consisting of slate panels with the instruments and control apparatus mounted on the front and with the busbars and main connections at the back. The A.C. panels are fitted with indicating lamps, and the overload coils are provided with time limits.

The arrangement of the D.C. board will be seen from Fig. 15, which shows the circuit breakers mounted on the upper panels, and the instruments and knife switches mounted below.

It will be noted from the foregoing that the arrangement of the high-tension and low-tension switchgear is such as to reduce the possibility of fire risk to a minimum, and the oil switches, which, after all, are the pivot of any large A.C. system, are of ample design and breaking capacity to take care of any conditions which are likely to arise, or even which can possibly arise.

The Metering Equipment.

In the design of this power station considerable attention has been paid to the metering equipment in order that an accurate check may be kept both on the overall thermal performance and the individual operation of the steam-raising and generating plant.

As already described in connection with the coal-handling plant, coal is weighed whilst it is being unloaded from trucks or barges, and again as it is being passed to the boiler-house bunkers by means of the skip hoist. These records furnish a check between the amount purchased and the amount received, and also by the method of difference show the amount held in storage from time to time.

In the boiler house the individual performance of the boiler units is recorded on metering boards each carrying the following instruments :—

(*a*) Steam flow indicator and recorder.
(*b*) Recording steam pressure gauge.
(*c*) Draught gauge.
(*d*) CO_2 indicator.
(*e*) Six-point temperature indicator.

The CO_2 indicators are connected electrically to recording instruments in the superintendent's office.

The thermometers of the six-point temperature indicators are arranged to measure the temperatures of the flue gases and water entering and leaving the economizers and the temperature of the steam leaving the superheaters.

The electrical units generated by the main sets and distributed from the station busbars are recorded by kilowatt-hour meters arranged on the control-desk in the switch room.

Recording Venturi meters have been introduced into the canal bye-pass system to show the quantity of water taken from and returned to the canal, and thus also the amount of canal water which has been used in the cooling towers as make-up for evaporation.

In conclusion, the author wishes to express his grateful thanks to Mr. P. P. Wheelwright for the assistance and facilities afforded him at the site.

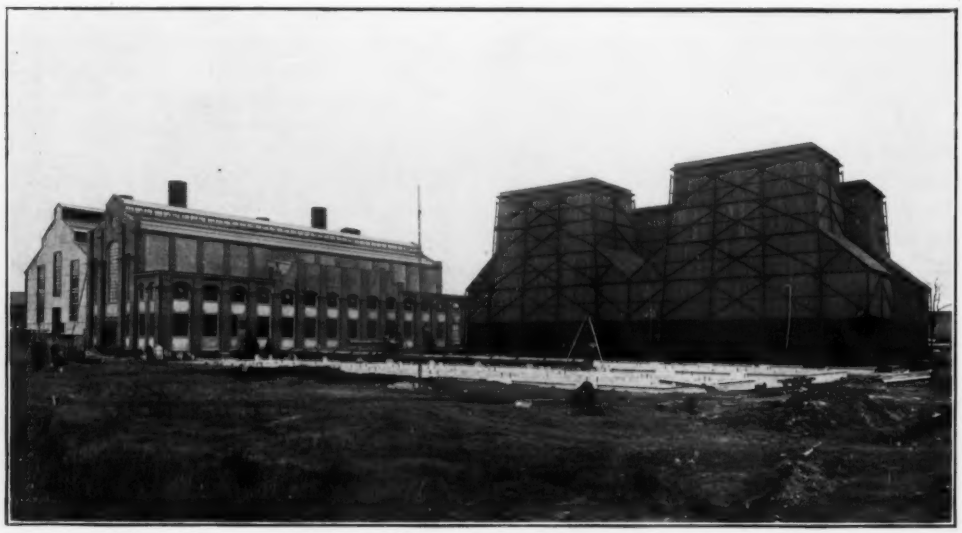
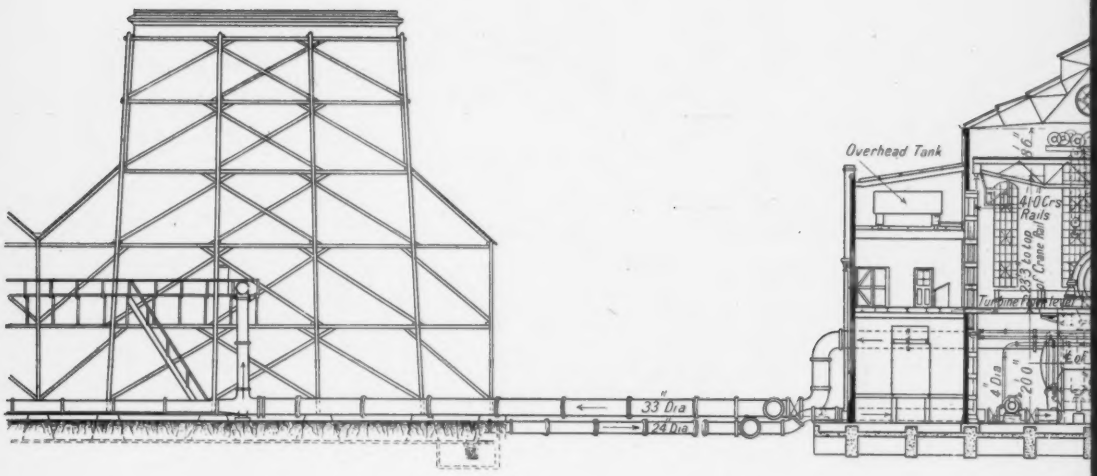
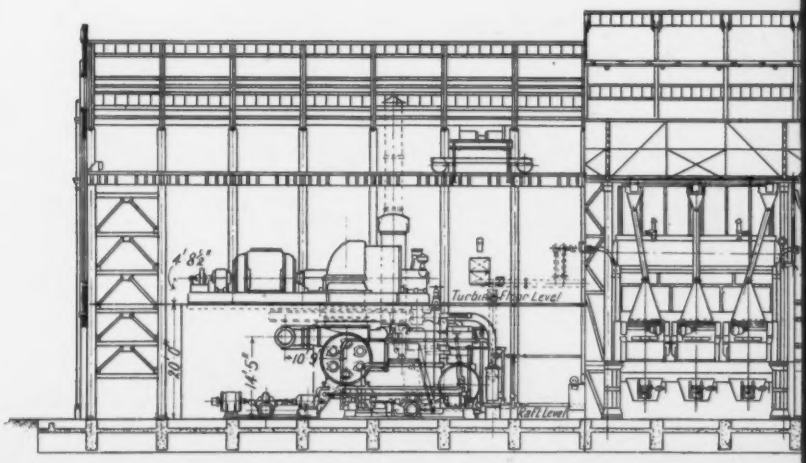


FIG. 19. THE POWER STATION FROM THE SOUTH SHOWING COOLING TOWER FOUNDATIONS IN FOREGROUND.

THE BLACKBURN (E

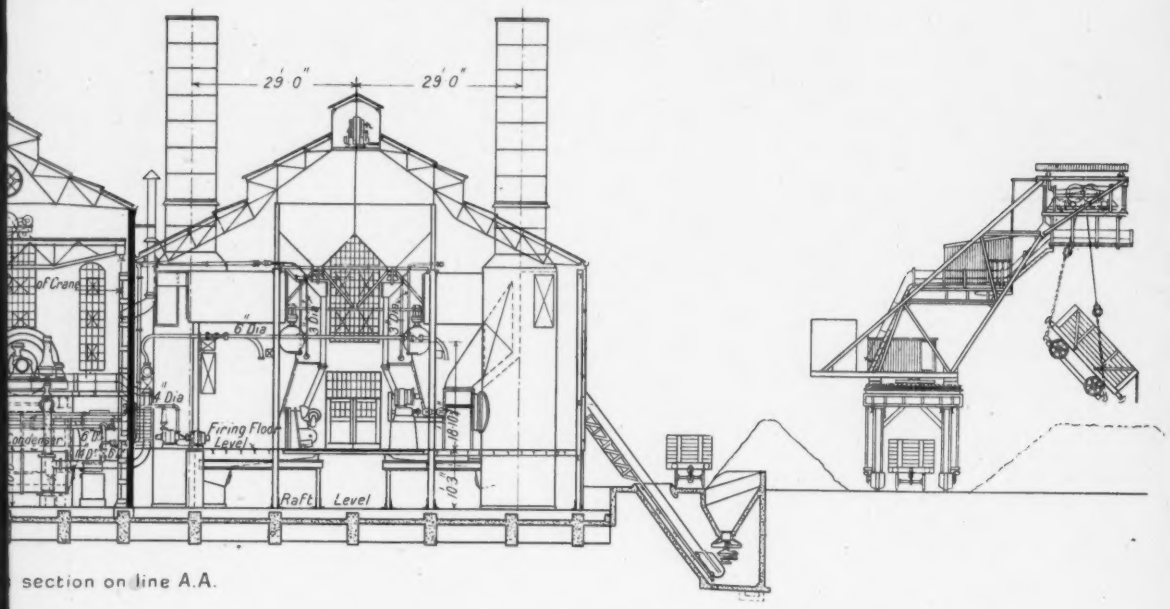


Cross

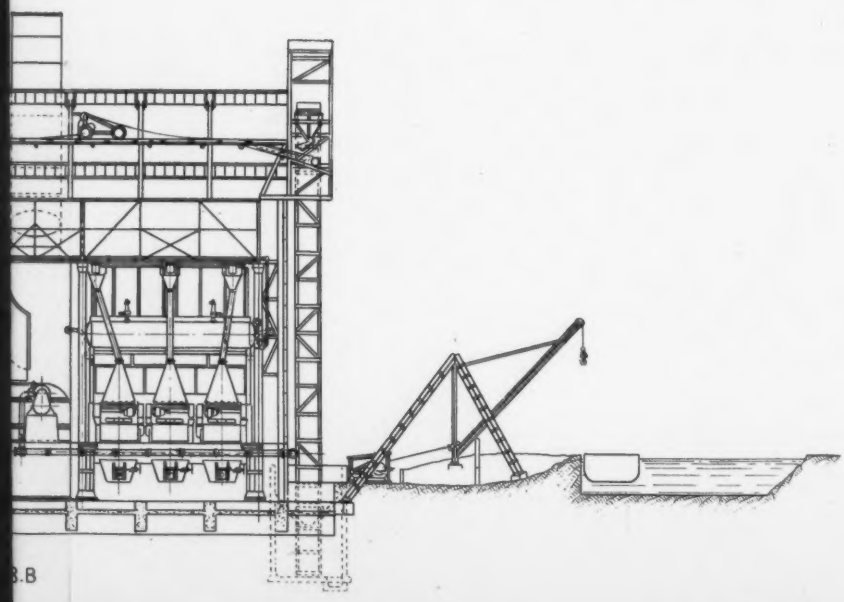


Longitudinal Elevation on Line

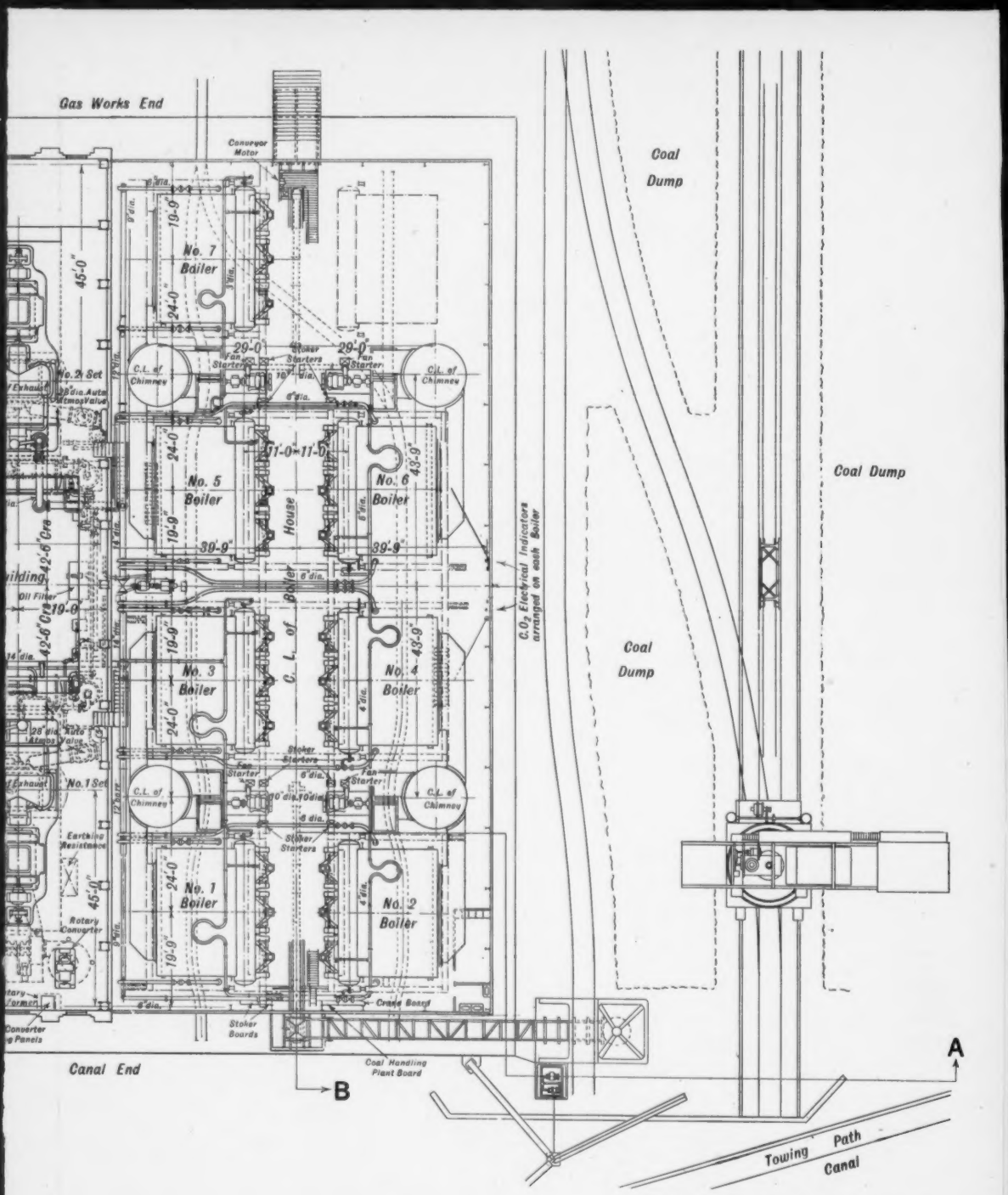
AST) POWER STATION

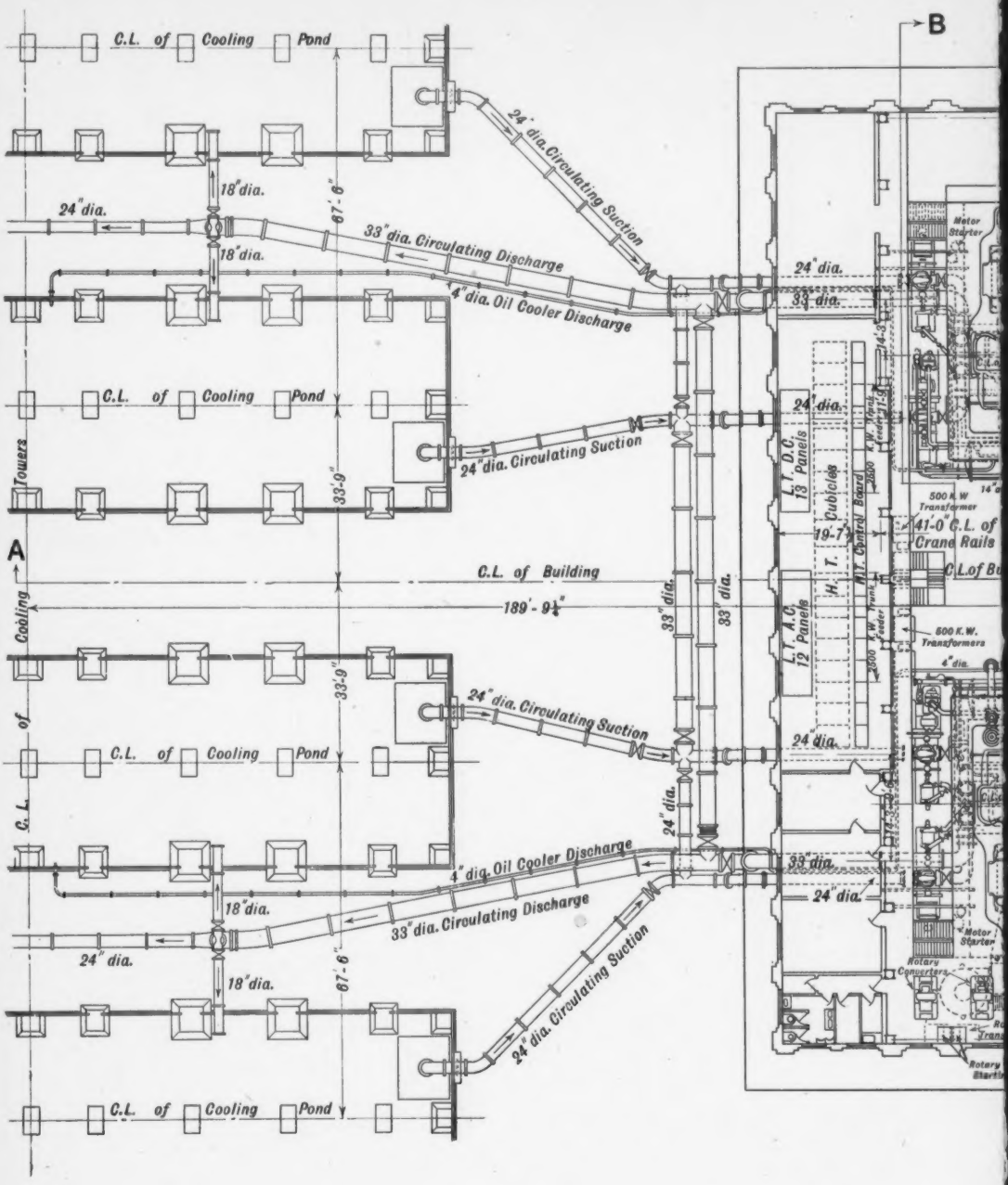


section on line A.A.



B.B


Gas Works End
Canal End
Coal Dump
Coal Dump
Coal Dump
No. 7 Boiler
No. 6 Boiler
No. 5 Boiler
No. 4 Boiler
No. 3 Boiler
No. 2 Boiler
No. 1 Boiler
C. L. of Boiler House
C.O2 Electrical Indicators arranged on each Boiler
Towing Path
Canal
A
B



[To face page 26]

The English Electric Camshaft Control.

In traction control apparatus there are two considerations of decisive importance both to railway engineers and to manufacturers. These are that the system must be reliable and capable of being readily and economically maintained.

The English Electric Company have had these considerations in mind throughout the development of their form of control for heavy locomotives and multiple unit stock. The control operations are mechanically effected by a motor-driven camshaft instead of by solenoids with their consequent complication of electrical interlocks.

The apparatus has been designed not only for reliability, but for reliability with the lowest possible maintenance cost. There is nothing in the apparatus which requires to be made and maintained to the same exceptional degree of accuracy as the air parts of an electro-pneumatic control, and there is, therefore, no need to employ in its maintenance any highly skilled workmen.

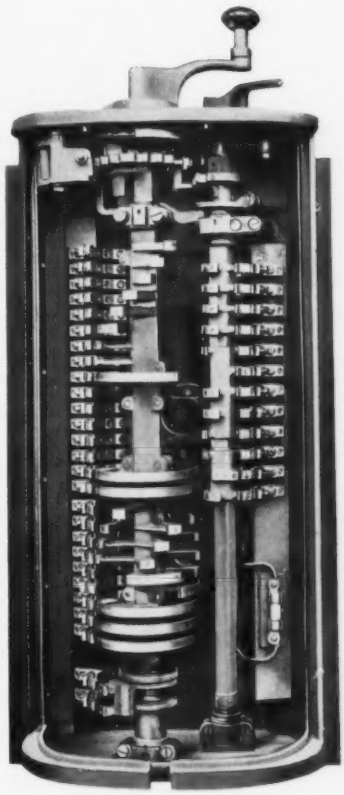


FIG. 1. MASTER CONTROLLER.

The camshaft principle is used by the English Electric Company for all heavy traction equipments, whether for locomotives or motor coaches. The particular apparatus illustrated and described in this article is for a locomotive equipped with four 350-H.P. motors, arranged for field control and regenerative braking. The motors are wound for 1,500 volts, so that each pair is operated by one set of camshaft control. It will be clear that for locomotives not equipped with regenerative braking there is a reduction in the amount of apparatus required, *i.e.*, the motor-generator set consists of two units instead of three. For motor coach equipments the horse power of the motors is smaller and the number of control notches fewer, and the whole of the apparatus is accordingly very much reduced in quantity and size.

The control is equally well adapted for all voltages; it is usual to have a motor-generator set for all supply voltages higher than 600.

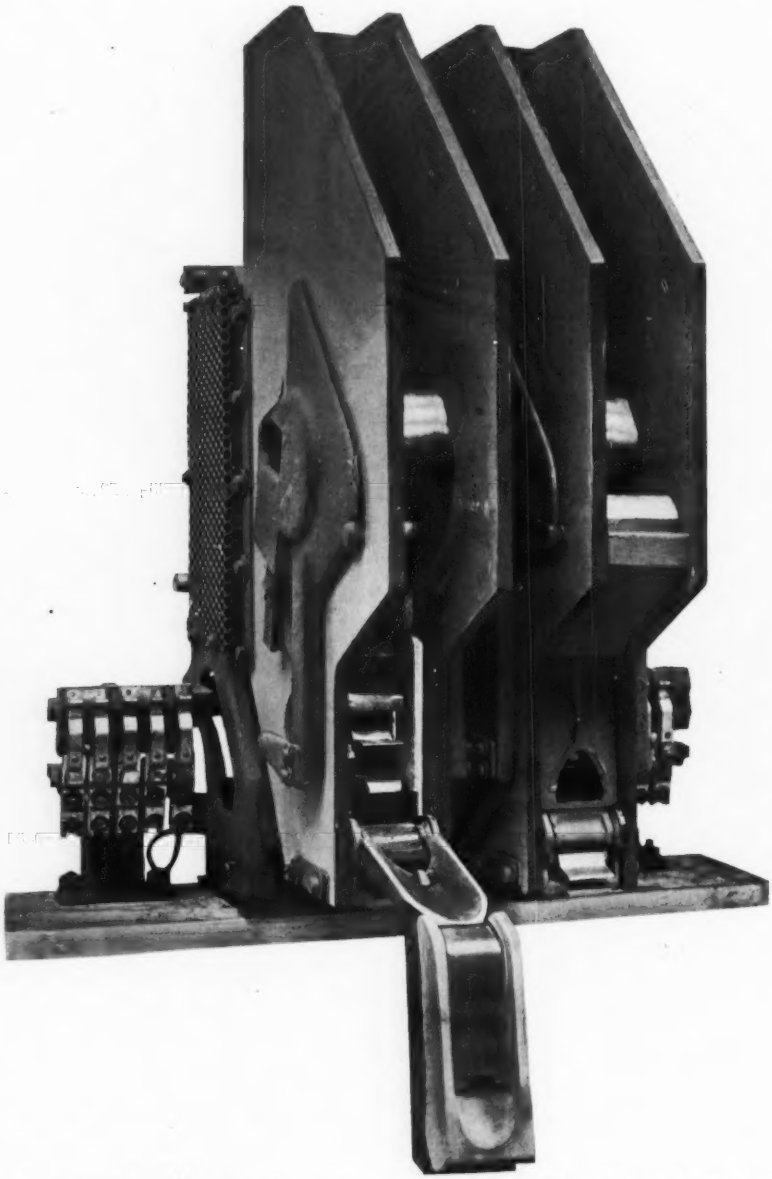


FIG. 2. ELECTROMAGNETIC LINE SWITCHES FITTED WITH "D.K." METALLIC-SHIELD BLOW-OUTS.
One Arc Shield shown lowered to expose contacts.

THE MAIN CIRCUIT.

The control for one unit consists of the following apparatus, the items being given in order, starting from the incoming lead from the pantograph and choking coil.

An Isolating Switch (Fig. 4) suitably interlocked with the doors of a H.T. compartment, and

A Main Fuse.

An Overload Relay (Fig. 3).

Two magnetically operated Line Switches in series (Fig. 2).

The overload relay opens these two switches in cases of overload. The switches are fitted with the "D.K." metallic-shield blow-out and are closed against a spring, so that they have no time lag in opening when the energizing current is broken.

The Camshaft Controller (Fig. 5).

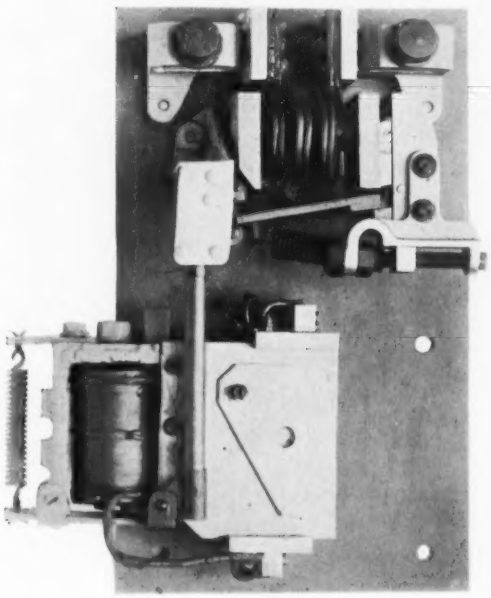


FIG. 3. OVERLOAD RELAY.

FIG. 4. MAIN ISOLATING SWITCH AND FUSE.

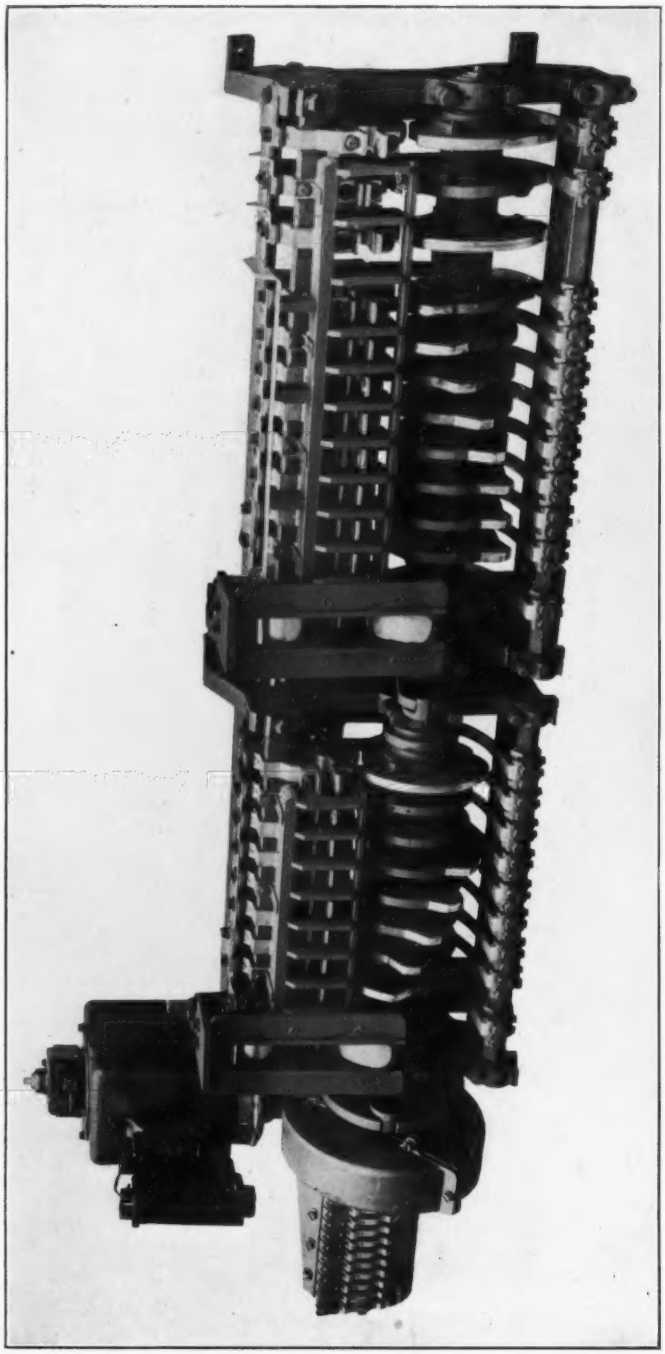


FIG. 5. CAMSHAFT CONTROLLER, SHOWING DRIVING MOTOR AND POSITION REGULATOR ON LEFT.
The circuit-breaking contactors are recognizable by their "D.K." Metallic-Shield Blow-outs and Arc Shields.

The Magnetically-operated Reverser (Figs. 8 & 9), which is in the main circuit between the main motor armatures and fields.

THE CAMSHAFT CONTROLLER.

The camshaft controller consists of a number of steel cams, which are mounted on a mica insulated steel shaft driven by an electric motor through a flexible drive and worm gearing. The cams are set at different angles and each one in its turn closes a contactor. On an extension of the shaft is a drum-type switch called the position regulator (shown on the left of the apparatus in Fig. 5). The closing of the camshaft contactors regulates the amount of starting resistance in the main circuit and also determines the grouping of the main motors. It will be noted that the progression of the camshaft is entirely mechanical, so that no interlocking is required to prevent the contactors closing in the wrong order; the progression is definitely determined and there is no possibility of incorrect operation.

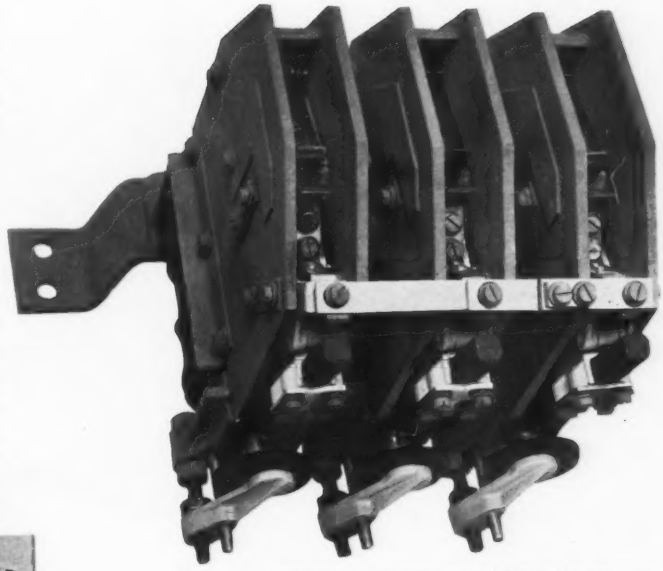


FIG. 6. AUTOMATIC STARTER FOR MOTOR-GENERATOR SET.

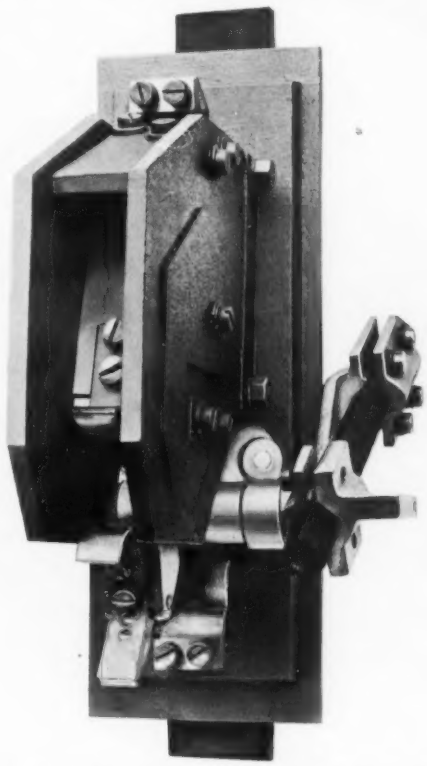


FIG. 7. ISOLATING SWITCH FOR MOTOR-GENERATOR.

An interlock is provided on the line switches, so that the camshaft cannot begin to rotate in a forward direction until the line switches have closed, or backwards until the line switches have opened. Hence the main circuit is always made and broken on the line switches alone, and the camshaft contactors require neither blow-outs nor arc shields.

For working on 600 volts the "bridge" system of control is used, but for higher voltages

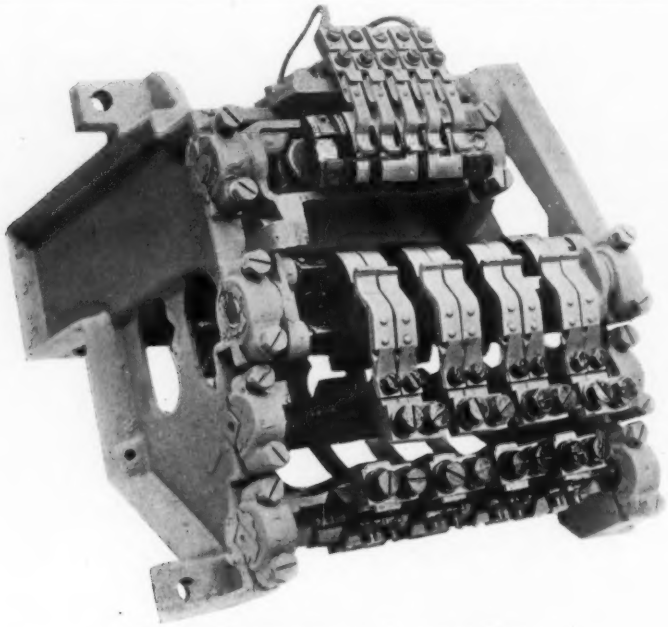


FIG. 8. ELECTROMAGNETIC REVERSING SWITCH.

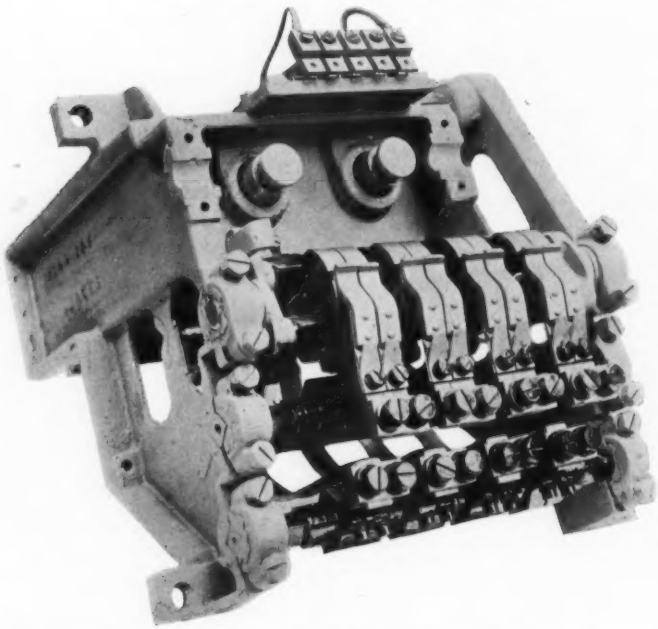


FIG. 9. ELECTROMAGNETIC REVERSING SWITCH WITH OPERATING PLUNGERS EXPOSED TO VIEW.

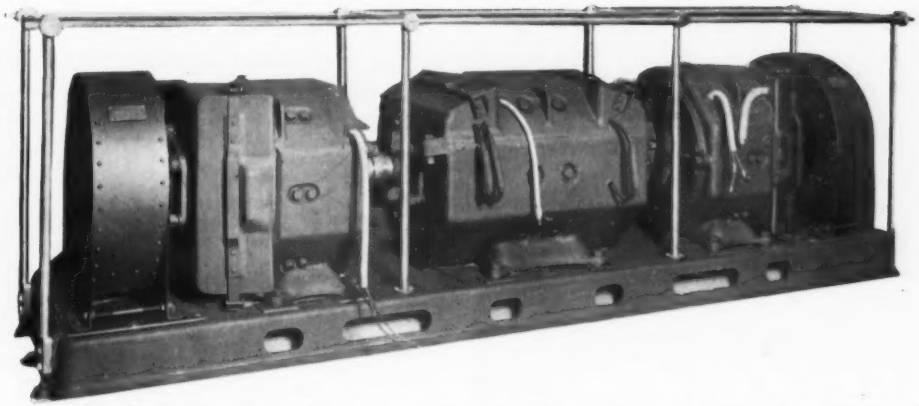


FIG. 10. MOTOR-GENERATOR SET SUPPLYING CONTROL CIRCUITS AND DRIVING VENTILATING FANS.

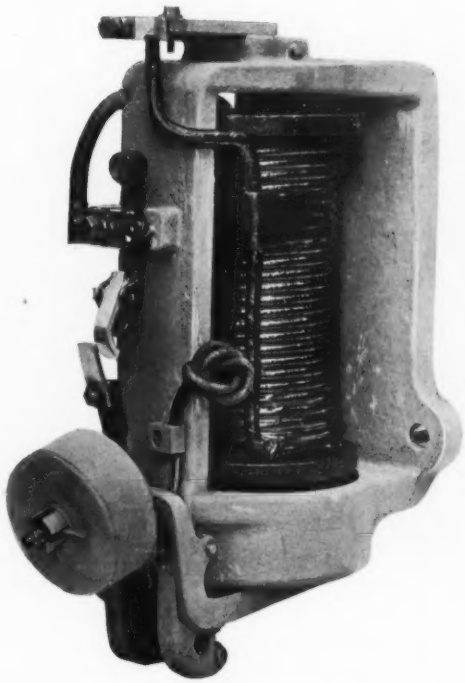


FIG. 11. REVERSE-CURRENT RELAY.

The English Electric Company's practice is to keep the field and interpole coils of the main motors permanently earthed even in the transition stage from series to parallel. By this means the potential across these coils is kept small and the maintenance on them consequently reduced to nothing. This arrangement makes it necessary to fit two of the contactors, on which a small equalizing current has to be broken, with blow-outs, and these will be clearly seen in Fig. 5.

THE CONTROL CIRCUIT.

The apparatus just described is controlled from a low voltage supply taken from a motor-generator set (Fig. 10). The motor of this set is driven from the line supply, the controlling apparatus being :—

An Isolating Switch (Fig. 7) interlocked with the doors of a H.T. compartment.

An Automatic Starter (Fig. 6) with three small contactors and a starting resistance.

A Reverse-current Relay (Fig. 11). If the line voltage drops suddenly the inertia of the set would cause the motor to feed back to the line and this relay inserts resistance into the circuit. thus safeguarding the motor.

The motor-generator here illustrated consists of a H.T. motor (the central machine) driving a 120-volt generator (shown on the left) and a variable-voltage generator (shown on the right). Blowers are fixed at both ends of the set to supply the air for ventilating the main motors and the motor-generator set itself. The 120-volt generator supplies current for the control, and in this instance has also four notches for field control of the main motors.

From the master controller the control current passes through the train wires and the position regulator to the camshaft motor. When the camshaft has progressed to a position defined by the master controller the armature of the camshaft motor is short-circuited by a

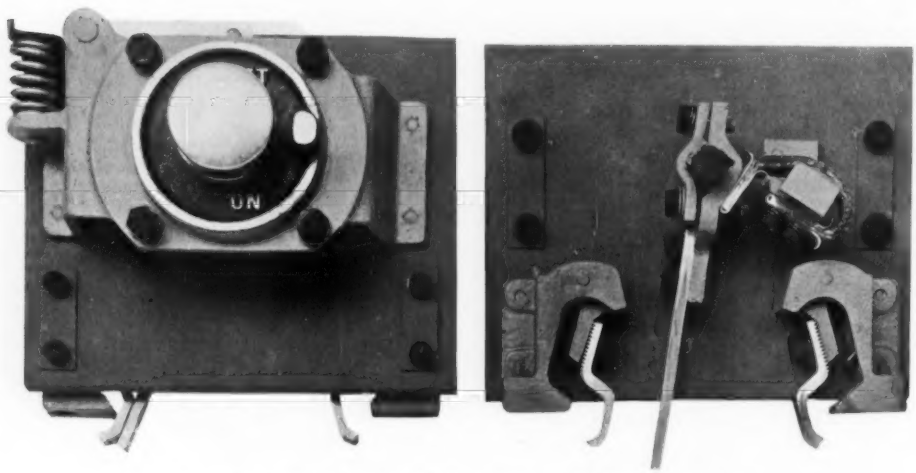


FIG. 12 SETTING AND CONTROL SWITCH TO MASTER CONTROLLER.

for lighting, for the fields of both the other machines in the set and in this instance for the brake compressor motors. The variable-voltage generator supplies current for the fields of the main motors when the locomotive is regenerating. The control during regeneration is operated from the master controller by varying the excitation of the variable-voltage generator.

The 120-volt generator supplies current through a paralleling switch to a train wire from which current is taken in the driving cab through a Setting and Control Switch (Fig. 12) to the Master Controller (Fig. 1). The master controller is arranged for power and braking relay; the energizing of this relay is determined by the position regulator. The short-circuiting of the camshaft motor armature brings the camshaft to rest positively and definitely; the stop is made without any hesitation or over-running.

A no-volt relay is provided, so that, in the event of failure of the line supply, the master controller must be brought to the zero position when the supply is restored before power can again be applied to the motors.

The line switches are fitted with a setting coil operated from the setting switch mentioned above, and they are tripped by bringing the

master controller to zero. The line switches can only be set when the master controller is in the " off " position.

ELECTRIC BRAKING.

This type of control is easily adapted for regenerative or rheostatic braking. The equipment described above is for regenerative braking for the Chemins de Fer du Midi. The English Electric Company are also manufacturing main line locomotives for the Midland Railway of New Zealand fitted with rheostatic braking.

FIELD SHUNTING.

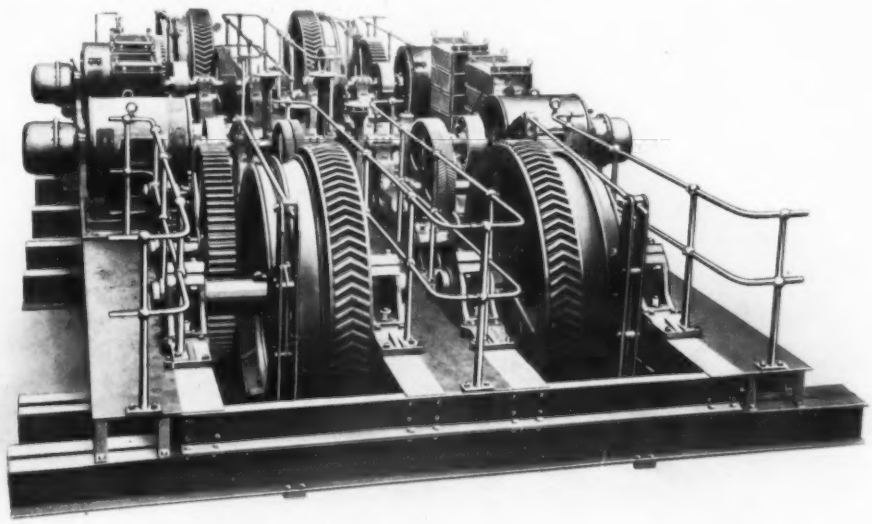
For field control of the main motors for locomotives separate magnetically operated contactors are used, so that the driver can notch backwards and forwards on the field shunting notches at will without tripping the line switches. But for motor coach equipments, in order to make the apparatus as simple as possible, the field shunting is done by means of cams mounted on the camshaft. It is obvious that either method can be used for both locomotives and motor coaches ; the determining consideration is the condition of service.

CONSTRUCTION.

A non-inflammable construction has been adopted throughout and all operating spindles and finger supports consist of steel with mica insulation.

The line breakers and the two contactors on the camshaft which break current are fitted with " D.K." metallic-shield blow-outs.

Special attention has been paid to the interchangeability of parts with a view to keeping down the number of spares required. At the same time, while all wearing parts are ample, they are designed so as to facilitate renewal when necessary.



The above illustration shows a group of electrically-driven Endless Haulage Gears mounted on one framework and equipped with four English Electric three-phase Induction Motors, each of 75 H.P., 585 R.P.M. at 2,000 Volts, 50 Cycles. The Haulage Gears were supplied by Messrs. John Wood & Sons, Ltd.

Main Line Electrification in New Zealand.

The illustrations on this and the opposite pages indicate to some extent the progress which is being made in the manufacture at the Company's Preston Works of the material for the electrification of the Arthur's Pass section of the Midland Railway of New Zealand. At a later date a full description of this important contract will appear in this Journal. The main line locomotives will each be equipped with four 1,500 volt, 175 H.P. direct-current motors, and Figs. 1 and 2 show respectively one of the completed motors and a group of the component parts. These motors are of the ventilated type, being particularly robust in construction and are designed for a gear ratio of 68 to 15.

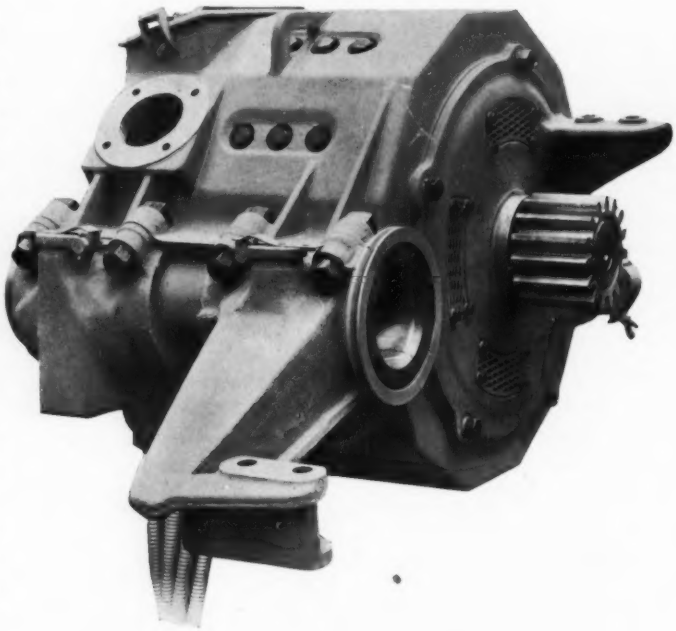


FIG. 1.

FIG. 2.

Figs. 3 and 4 are views of one of the special battery locomotives which will be used in connection with the inspection and maintenance of the overhead line. The equipment consists of four 440-volt, 50-H.P. D.K. 30 motors, having a gear ratio of 83 to 15. There is an inspection platform on top of the cab which can be raised or lowered by means of suitable gearing and is provided with collapsible guard railing.

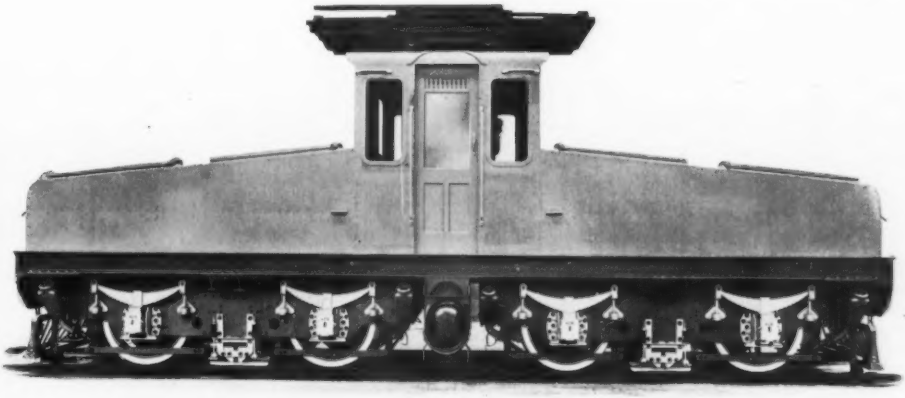


FIG. 3.

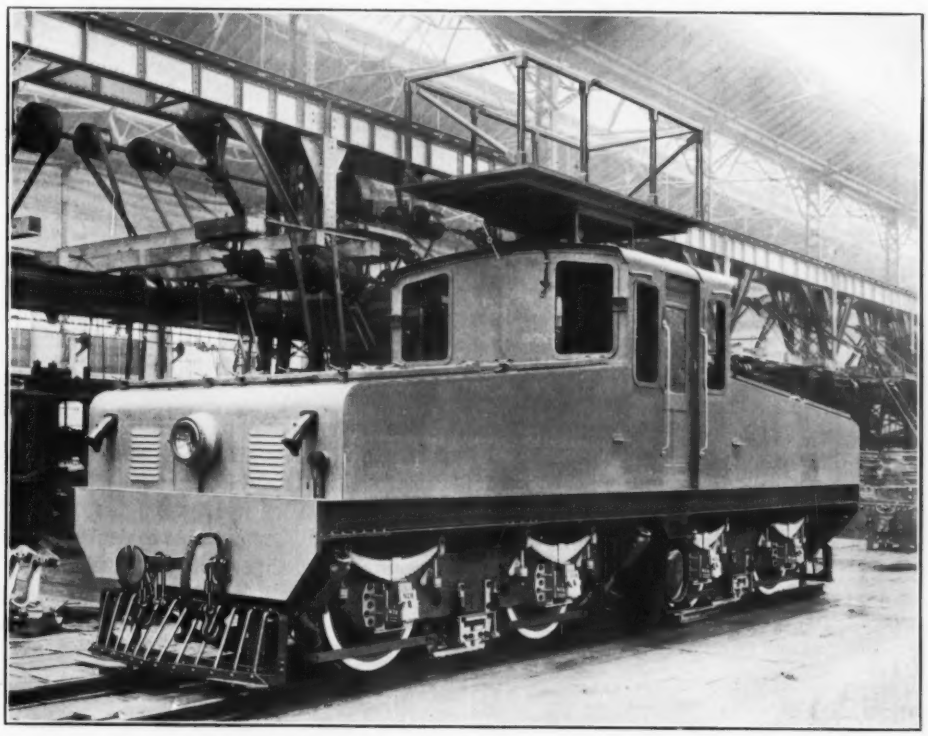


FIG. 4.

Turbo-Blowers.

By J. A. Osborn.

The successful development of the steam turbine, especially of the impulse type, in a practical and reliable form has undoubtedly led engineers to consider, wherever possible, the replacement of reciprocating machinery by the equivalent rotary type. The way in which the steam turbine has almost completely superseded the reciprocating engine is a matter of history, as is also the persistent advance of the centrifugal water pump into fields previously held by piston pumps. In a similar way the turbo-blower has in recent years been more and more widely adopted for blast furnace work, until it has now practically displaced the old type of reciprocating blowing engine.

The primary reason for this radical change is to be found in the compactness of the turbo-blower which, in conjunction with the lightness of the foundations and the small size of the necessary buildings, has enabled the initial cost of the installation to be reduced to a very low figure. An idea of the saving of space with the rotary machine may be derived from the fact that three turbo-blowers can be very comfortably installed in a Power Station in the space necessary for one gas engine driven reciprocating blower of one-third of the total capacity.

It is universally conceded that centrifugal blowers are extremely reliable in operation. This is due to the great simplicity of the principle employed and the complete absence of reciprocating parts, valves and intricate valve gear. The efficiency of a turbo-blower remains constant over long periods of service and is not appreciably affected by wear and tear of the moving parts as is the case with reciprocating machinery; this fact, combined with the efficient system of forced lubrication employed for all bearings, reduces the maintenance and attendance charges to a minimum. These features are of special importance for the duty of supplying air to blast furnaces since it is usual for the blower to run continuously for very long periods, so that an opportunity of opening up for inspection seldom occurs.

Although the gas engine blower using blast furnace gas has a higher thermodynamic efficiency, it has all the inherent mechanical disadvantages of the reciprocating steam engine. The ever-present problem of cleaning effectively blast furnace gas, together with the high maintenance and attendance charges, all tend to place the gas engine second to the turbo-blower in commercial economy. The extreme flexibility of the turbo-blower, its capacity for taking overloads, and the small speed variations required to meet large and varied changes in load, are factors which have led to its rapidly increasing popularity.

Since the application of turbo-blowers to the iron and steel industries, it has been observed that the furnaces show less tendency to stick than previously, and this has been found to be a direct result of the more uniform air flow and the entire absence of pulsations. It is of interest to note that this same characteristic has given the turbo-blower an unique advantage in connection with glass-blowing installations, where a steady non-pulsating air supply is absolutely essential.

The commercial field of application for rotary air or gas machines, comprising turbo-compressors, turbo-blowers and exhausters, is very extensive, as apart from the advantages already stated they are able to deal with a fluid containing a small percentage of dust. This has no detrimental action upon the rotary machine, although it would soon destroy the efficiency and cause the ultimate breakdown of the reciprocating type. In connection with the handling of grain, ashes and even coal by means of the suction process, these installations have been made very successful by using

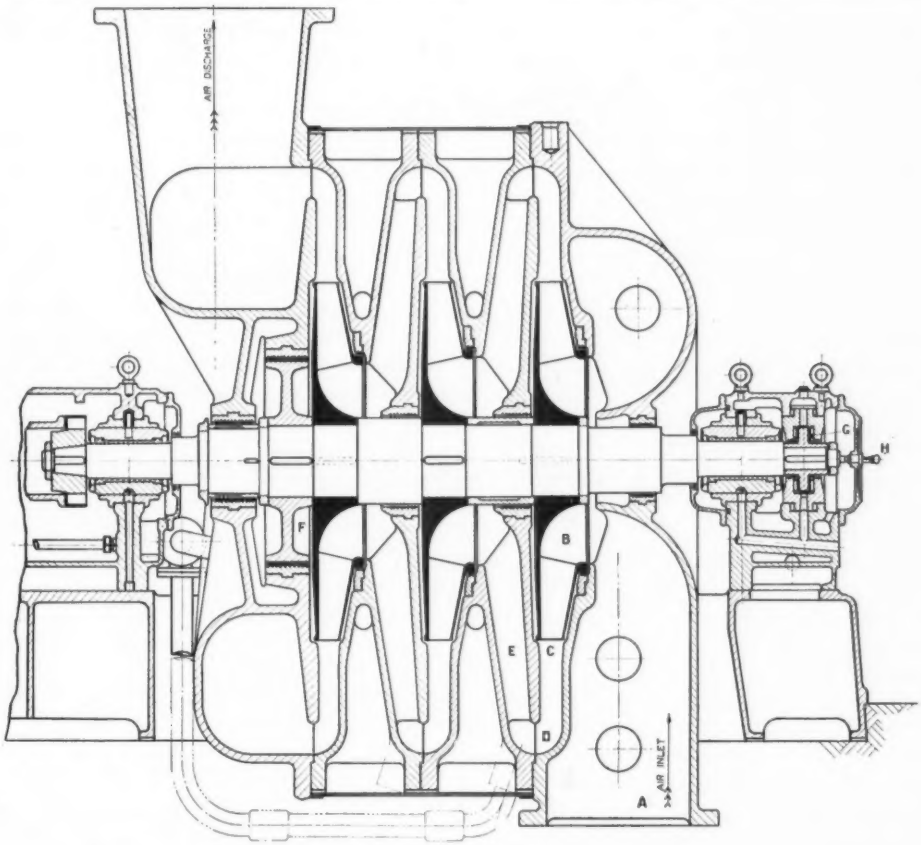


FIG. 1. SECTION OF THREE-STAGE TURBO-BLOWER.

turbo-exhausters, which have maintained the required vacuum under extremely trying conditions. The light weight and small space occupied, enables complete equipments in some cases to be assembled on portable carriages such as railway trucks, motor lorries or pontoons.

The turbo or centrifugal blower is an ideal rotary machine and when coupled direct to a steam turbine the combined unit makes a very reliable, elastic and cheap means of obtaining efficiently the compression of air or gas. It can also be driven by an electric or petrol motor coupled direct when the speed permits, or alternatively through increasing gears. The principle of operation is generally similar to that of the multi-stage centrifugal water pump, though important variations of design have of necessity been introduced owing to the difference in the densities of the working fluids. As is well known, the terminal pressure varies directly with the density for a constant peripheral speed, and since water is over 800 times as heavy as air, it will be readily understood why so many stages are necessary in turbo-blowers for comparatively small pressures.

A further point which greatly affects the design of the turbo-blower is the change of density caused by the increasing pressure and temperature. This means that the pressure per stage with constant peripheral speed is

continually increasing, whereas in a water pump the increase in pressure per stage is constant throughout. The change in the density of the air has to be carefully considered when dealing with high pressures, but for low pressures it does not greatly affect the design, except to procure a reduction in the width of the air channels of the rotor and diffuser. On the other hand, in the case of a turbo-exhauster or gas compressor, the density of the air or gas at the inlet of the machine is of considerable importance and must be taken into account, since it directly influences the speed and number of impellers to be employed.

Description of the English Electric Turbo-Blower.

As will be seen from Fig. 1 the turbo-blower consists of a shaft carrying one or more impellers which rotate inside a fixed body or casing. Air is inhaled at the inlet A and passes into the eye of the first impeller B from which it enters the vanes without shock. It is then forced along the curved surface of the vanes until it is finally ejected at the wheel periphery into a diffuser C. This diffuser is an annulus of constant width formed in the casing, its function being to collect the discharged air and by uniformly decreasing its velocity to transform the velocity into pressure.

The air on leaving the diffuser at D is turned back and flows into a return chamber or annulus E fitted with special guides arranged to collect the air and lead it axially into the next impeller. This cycle of operations is continued through all the impellers until the last diffuser is reached, when the air is discharged into the volute or discharge chamber. This chamber is designed with a gradually increasing cross-sectional area, in order that all the air leaving the diffuser periphery may be collected as far as possible with uniform velocity, and guided through the final circular outlet into the air main. It will be noted that the air after being inhaled passes through the machine with as little shock as possible, all the passages being sufficiently large and well rounded, so that there are no abrupt or tortuous channels which would have a detrimental effect upon the efficiency.

The blower being of the single-flow type, there is an out-of-balance force at the back of the impellers tending to push the rotor towards the inlet of the machine. This force is counteracted by means of a carefully proportioned balance piston shown at F (Fig. 1). The balance piston rotates in a chamber, the back of which is connected by a pipe with either the inlet or any intermediate stage which has a suitable pressure for balancing purposes. A valve is fitted in the pipe for making any finer adjustment to the balancing pressure which may be necessary. In order to obtain correct alignment and to take care of any sudden change of load on the blower, a Michell thrust block G of ample proportions is fitted in the outer bearing pedestal and a small thrust indicator H is provided on the pedestal end cover, so that during running the wear on the thrust, if any, can easily be observed.

For pressures below 14 lbs. per square inch no provision is made for cooling the air or gas, unless it is particularly desirable that the final temperature should be kept low. It is, however, general practice to provide water cooling for pressures above 14 lbs. per square inch, in order to reduce the power required for compression and keep the temperature within safe working limits. Referring to Fig. 2, water is fed into the annulus J formed between the return chamber E and diffuser D. The water space is self-contained, each half body-ring being blanked off on the horizontal joint. Water is admitted separately into each half of every body-ring and is discharged in a similar manner on the opposite side of the machine. Each body-ring is provided with cleaning holes in the most accessible positions and also with drain bosses on the bottom half and air connections on the top half.

It will be seen that the water-cooling arrangements are exceedingly simple, long or tortuous passages being avoided and all water connections being arranged externally. The latter feature is of special importance, since in the event of leakage occurring at any of the joints

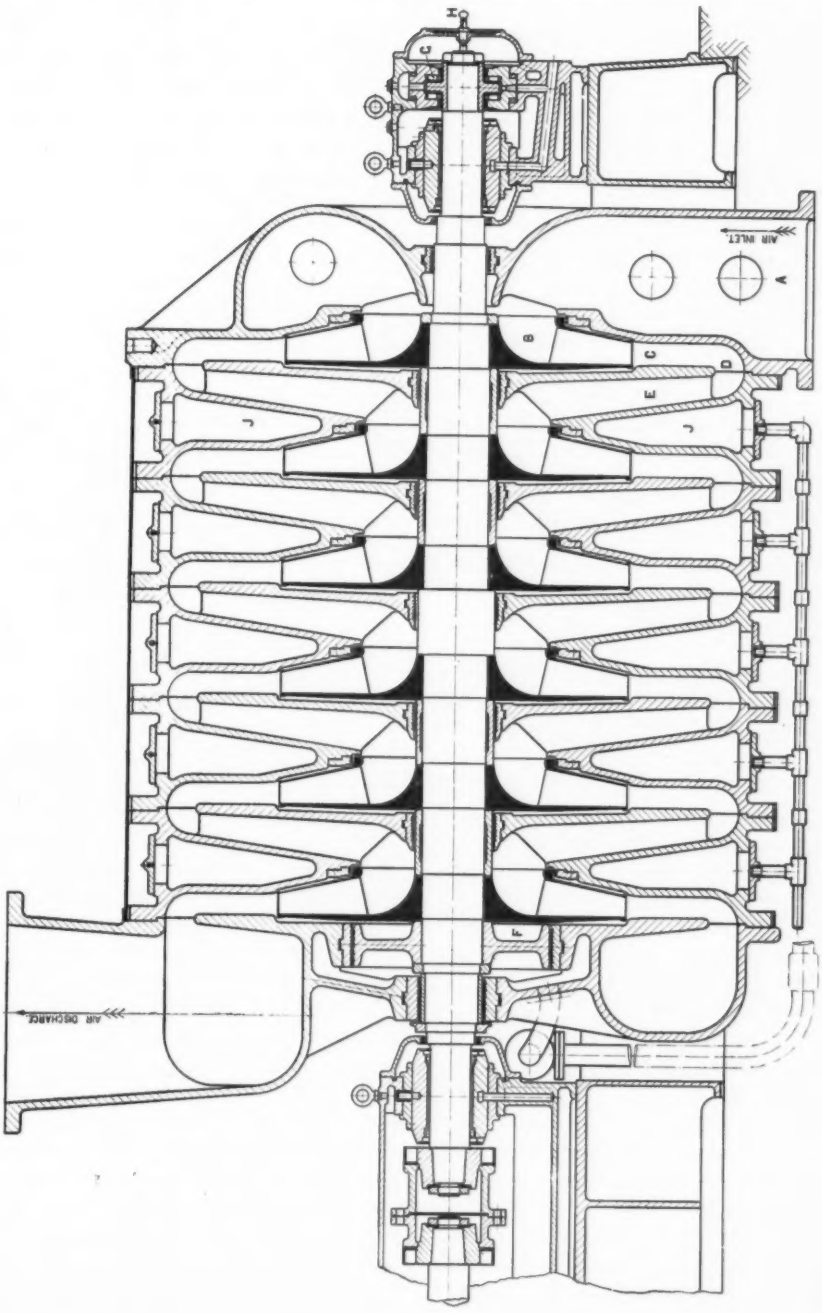


FIG. 2. SECTION OF WATER-COOLED SIX-STAGE TURBO-BLOWER.

it is impossible for water to get into the casing and mix with the air or gas. An alternative method is to cool the air by passing it round a water-cooled space inside the machine, or by specially arranged water tubes in the air path. The complications of these methods, however, and the possibility of delays in running caused by the necessity of opening up the machine should any internal part leak, have led The English Electric Company to adopt the method of body-ring cooling already described, the reliability of which is unquestioned.

In practically all uncooled English Electric machines the shaft is made "stiff," that is to say, the first critical speed of the rotor is considerably above the maximum running speed of the machine. With few exceptions, however, the larger number of stages required for the higher pressures of water-cooled machines prohibits the use of a stiff shaft, as its increased diameter would act adversely on the eye of the sideplate, which in its turn is limited by the diameter of the impeller. Such machines, therefore, if made with one casing necessitate the use of a flexible shaft so designed that the working range is well within the first and second critical speeds. If the use of a flexible shaft is to be avoided, the machine would have to be built in two casings, a design which is unnecessary and uncommercial to-day although it was frequently adopted in the earlier days of turbo-blower development.

It will here be of interest to discuss briefly the phenomenon known as pumping or surging, which is an inherent characteristic of all rotary air or gas blowers.

When a turbo-blower is run at any given speed and the volume is decreased to a certain limiting amount, the air reaches a point of maximum pressure and begins to surge or oscillate in the machine, breaking down completely the continuity of the supply of air or gas. The machine must never be allowed to remain long in this surging condition, as the repeated oscillations of the air would soon set up serious and dangerous vibrations. If the speed of rotation is reduced, the machine will right itself and go on delivering a constant stream of air until the volume delivered is again decreased to the surging point for that particular speed, when the machine will again become unstable. A glance at the pressure-volume characteristic curves, examples of which are given in Figure 3, will show the volume at which surging takes place, this being greater at higher pressures and falling gradually to zero for zero pressure.

In the working of blast furnaces the position of the surging limit is of extreme importance,

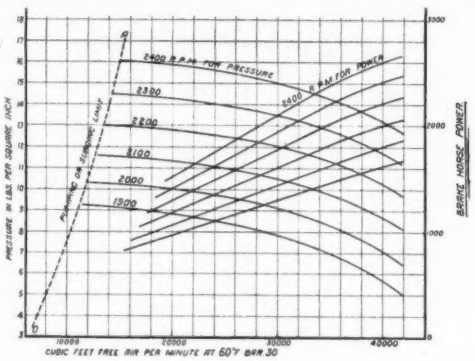


FIG. 3.

for when the furnace sticks, the air pressure rises and the volume diminishes, often very considerably below the normal duty. It is necessary, therefore, that the surging limit should be as remote as possible from the expected working conditions, for apart from its actual value it will be seen that the slope of the limit curve OA is directly opposed to the requirements of blast furnace working.

To overcome the difficulty of keeping the machine in continuous operation when blowing small volumes, it is found necessary in some types of blowers, where the design does not permit a low pumping limit, to adopt an automatic or hand-controlled device for regulating the volume. Usually a butterfly valve or a special type of gate valve is inserted in the air intake and is operated through a relay gear working in conjunction with a pressure governor or by hand. Such devices when arranged for

automatic control are not always dependable in operation and are, therefore, to be avoided whenever possible.

In some cases, if the surging limit is too near the working conditions, the blower has to continue to blow the normal air quantity for which it was designed and the surplus air not required by the furnace is discharged to atmosphere through a special relief valve. This arrangement, although satisfying the requirements of the furnace, is extremely wasteful for duties below the normal.

In the English Electric turbo-blower these points have been given special care, and the pumping limit is kept very low in relation to the normal duty and well inside the expected minimum air quantity required. This very low pumping characteristic is obtained without the use of any automatic or hand regulating gear, and as the efficiency remains fairly constant over the whole working range, it will be appreciated why these machines are so successful in meeting the requirements of present-day blast furnace demands.

FIG. 4. CONSTRUCTION OF IMPELLER.

It is usually found that for all normal requirements the easiest and most satisfactory way of governing the blower, when turbine driven, is by use of an ordinary constant speed governor having a larger range than is usually provided for a turbine driving a generator. By the aid of a characteristic chart based on the test results of the blower, giving the relation between volume, pressure and speed of rotation, the blower can be controlled directly from the turbine governor so as to give constant volume or pressure as required.

A special feature of the English Electric blower is the robust construction of the impellers, to which every care is given both in design and manufacture. This is an important point, since upon the design of the impellers depend to a large extent both the efficiency and reliability of the machine. As will be seen from Fig. 4, the impeller is formed from a solid forged steel disc to which are securely fastened by fitted rivets, a number of pressed steel vanes of channel section suitably curved to obtain flexibility of output. A steel cover or side plate of strong design is securely riveted to the opposite sides of the vanes, tying these firmly together and forming a complete impeller of the strongest possible construction. The impellers are separately balanced on an accurate balancing machine and are then hydraulically forced upon the shaft to form the finished rotor, as shown in Fig. 5. The whole rotor is then finally balanced before being assembled in the casing.

The casing consists of inlet and discharge chambers with a number of separate body-rings

of standard form to suit the number of impellers; it is of cast iron throughout and each body-ring is built up in one or more segments to form cells in which the impellers rotate. Each segment is jointed vertically for simplicity of design and ease of manufacture, and the whole casing is divided by a horizontal joint, so that the upper half can be lifted for inspection of the rotor without disturbing any other part of the blower.

As previously mentioned, the only rubbing surfaces are the bearings of the machine, all the glands for the shaft and impellers being of the labyrinth type, arranged for small clearances when the shaft is stiff, and with increased clearances when a flexible shaft is used.

The chief factor in determining the adoption of the design described above was that it resulted in a short stiff machine employing the minimum number of impellers. This design also involves the smallest possible variation from the use of standard components, and has the advantage that the number of parts to be held in stock is reduced to a minimum.

For blast furnace work the single-flow type of turbo-blower fulfils the requirements in practically every case, but where the machine is specially required to blow large volumes at small pressures a double-flow design is used, embodying one impeller arranged so that the air or gas enters on both sides and is discharged at the middle.

Installation.

The ideal method for blast furnace work is to connect one blower to each furnace, as much better regulation can be obtained than when air is supplied from a common main, owing to the varying conditions of working in the individual furnaces. In cases, however, where existing conditions make this impracticable, it is now the usual practice to insert a non-return valve in the air main as near as possible to each turbo-blower. The use of non-return valves has been found to be a necessary safeguard; before their adoption several accidents occurred owing to the driver neglecting to carry out correctly all the change-over operations.

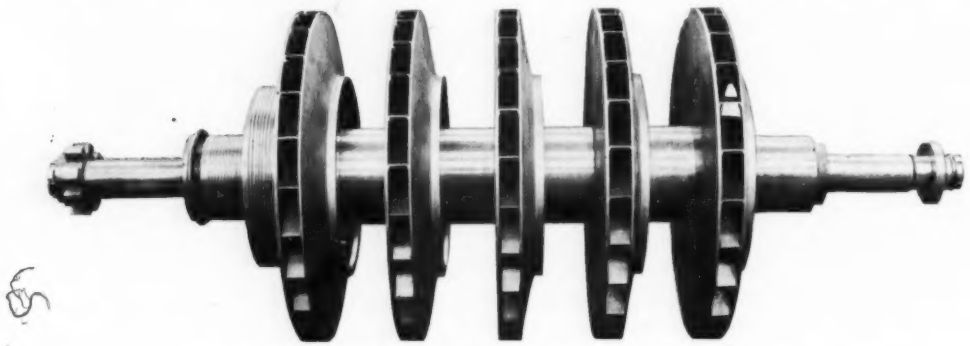


FIG. 5. COMPLETE ROTOR.

When several blowers are arranged to discharge into a common air main it has been customary to run the machines alternately so as to ensure that the stand-by machine is always ready for duty. In the past the practice was to fit a sluice valve to the delivery side of each blower, these valves being operated by hand when it was desired either to put the blower into service or to isolate it from the air main when shutting down.

On one occasion when two blower sets were in operation on a common air main the driver, in taking one of the sets out of commission, shut down the turbine but omitted to close

the air discharge sluice valve. In consequence, the high-pressure air entered the blower through the discharge opening, and forcing its way through the impellers, acted directly on the vanes and rotated the whole set in the opposite direction. It was extremely difficult to see that the direction of rotation had reversed, and the driver, noting that his steam stop valve was shut, merely thought the blower was taking longer than usual to come to rest. A serious smash was only averted by the failure of the oil supply, which caused the bearing to seize, as the rotary pump became useless when revolving in the opposite direction.

Fig. 6 shows the type of special non-return and relief valve that is recommended for insertion in the air main, its action being such that accidents of this type are impossible.

When starting up the blower the non-return valve is shut and the relief valve, which is kept fully open by the fact that its spindle is in direct contact with the non-return valve spindle, allows the air to pass out to the atmosphere. As the blower increases in speed and passes a larger volume of air, the pressure before the relief valve increases and builds up to the comparatively small extent necessary to lift the non-return valve. The external spring then closes the relief valve and the air is forced through the non-return valve into the air main.

Should any valve between the non-return valve and the furnace be closed inadvertently, the non-return valve drops on its seat and by direct contact forces open the relief valve, thus enabling the blower to keep in continuous operation by discharging the air to atmosphere. If the shutting of this external valve is not signalled to the Power House, the noise made by the air in passing through the relief valve gives sufficient indication to the driver to reduce the speed of the set until he knows the cause of the stoppage. Means are also provided for operating the relief valve by hand when

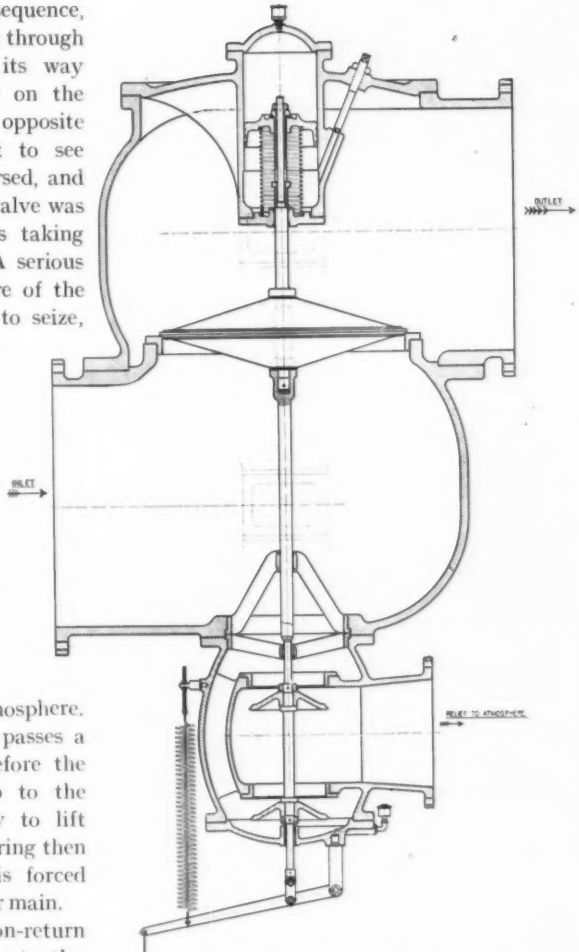


FIG. 6. NON-RETURN AND RELIEF VALVE.

starting up or closing down, if necessary.

The general arrangement of an English Electric turbo-blower installation is shown in Fig. 7, from which will be seen the method of admitting outside air through a duct in the concrete and the convenient arrangement of the sluice valve and automatic non-return and relief valve.

Method of Testing Turbo-Blowers.

On completion of manufacture all English

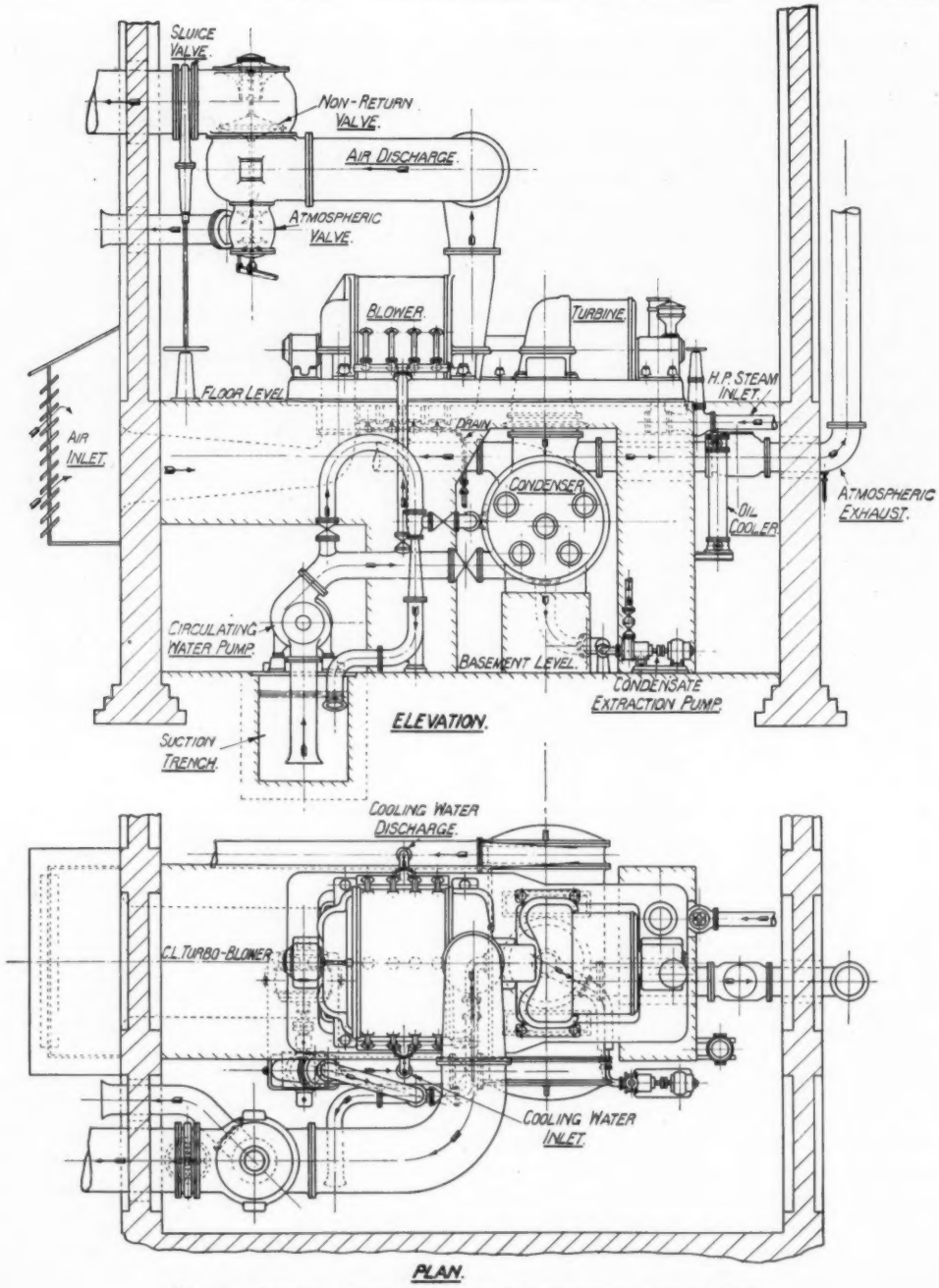


FIG. 7. GENERAL ARRANGEMENT OF TURBO-BLOWER INSTALLATION.

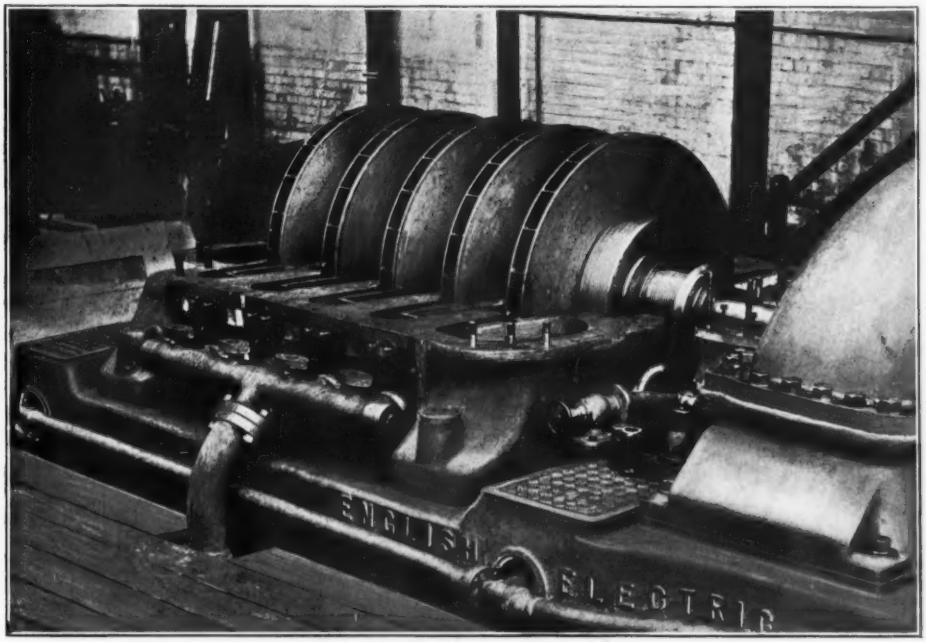


FIG. 8. TURBO-BLOWER IN COURSE OF ERECTION ON TEST-BED.

Electric turbo-blowers can be put through a running test at the Ordnance Works, Coventry, where facilities exist for running complete efficiency trials when required.

Fig. 9 shows a turbo-blower set on the test bed at Coventry. This machine is one recently supplied to the Shelton Iron Company for individual connection to a large blast furnace and is designed to deal with 40,000 cubic feet of free air per minute against a pressure of 15 lbs. per square inch; it has also to cover a wide range in volume at lower pressures. It is arranged for water cooling, as will be seen by reference to Figs. 8 and 9, the former showing the blower with the top half removed.

Tests on turbo-blowers for determining the relation between volume, pressure and efficiency are greatly facilitated by the fact that the air is delivered steadily in a constant stream, and it is thus possible to employ very simple measuring apparatus.

In some cases the air is drawn in through a nozzle placed in the blower intake, although this method is usually avoided unless the site conditions demand its adoption, owing to the difficulty of fitting satisfactory nozzles to the air intake. The general method adopted, therefore, is to discharge the air through a suitable nozzle fixed in the air main not less than about 20 ft. from the blower discharge, in order to avoid abrupt changes and obtain steady nozzle readings.

The method adopted by The English Electric Company is illustrated by Fig. 10, which shows the typical testing arrangement of a set on the Coventry test bed. The sluice valve on the blower outlet is used for regulating the volume in order to avoid changing the nozzles too often during a test. For the smaller machines taper

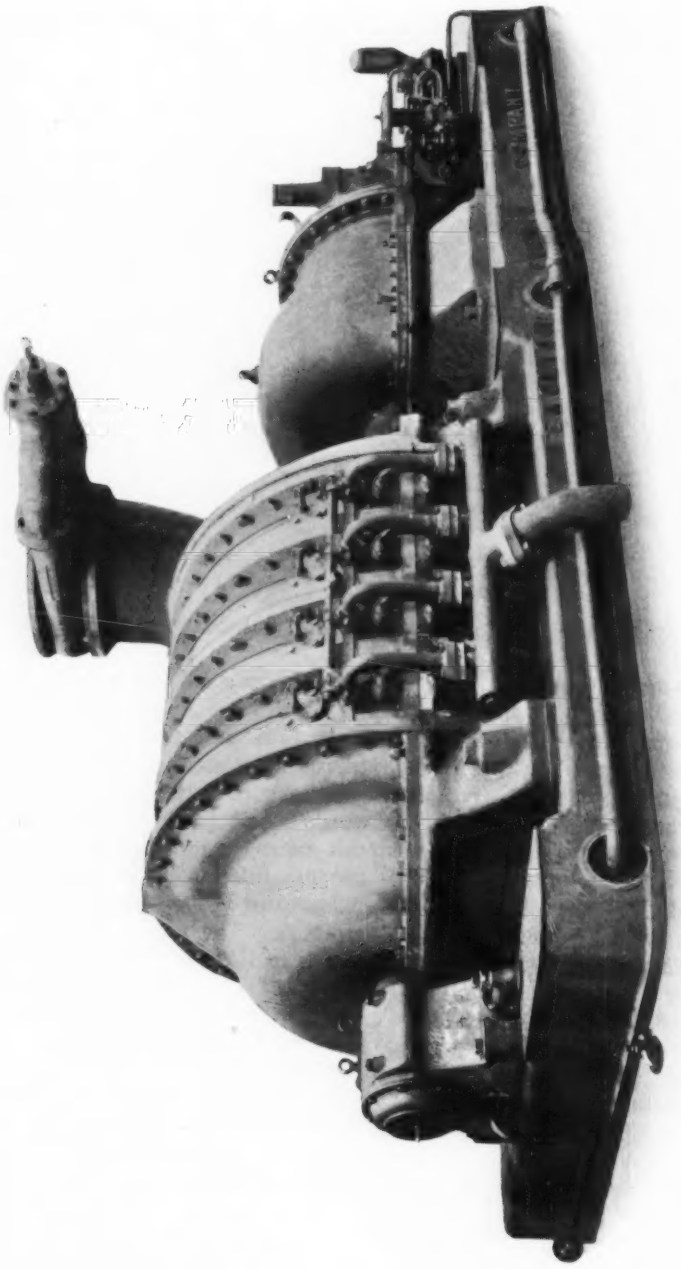


FIG. 9. TURBO-BLOWER ON TEST-BED.

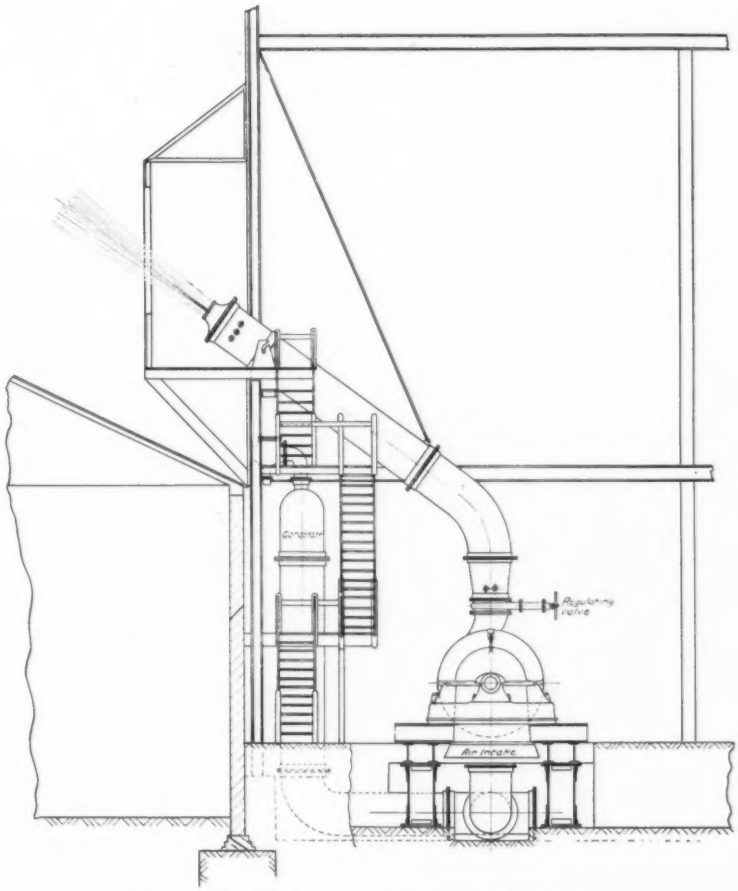


FIG. 10. METHOD OF TESTING TURBO-BLOWERS.

adapting pieces are fitted below the sluice valve and secured to the discharge flange of the blowers.

When testing a machine for volume and pressure a nozzle of suitable diameter for passing the normal air quantity is used, and variations of volume above or below this value are obtained as far as possible by hand regulation.

The prime mover, generally a turbine, is brought up to the calculated speed for the volume and pressure that is being tested. Periodical readings are taken of the barometer, air inlet temperature, air pressure and temperature of the blower outlet, the pressure and temperature just before the outlet of the nozzle, and the speed of the machine. When the blower is water-cooled, the quantity of water in gallons per minute and the inlet and outlet temperatures are also measured.

Having determined the pressure ratio before the nozzle and the temperature, the volume passing can be calculated according to the standard formulæ for the flow of air or gas through nozzles of known coefficient.

An Electric Winding Installation.

The English Electric Company have recently installed two electrically-driven winding engines at the Cronton Colliery of the Hulton Colliery Company, and these are now being used in connection with the sinking of two pit shafts.

The electrical equipment was manufactured at the Siemens Works of The English Electric Company, the high speed flywheels by Scott & Hodgson, Ltd., of Manchester, and the mechanical parts of the winders, such as drums, brake gear, etc., by Fraser & Chalmers, Ltd. The general arrangement of the plant is shown on the plan, Fig. 5, facing page 54.

The principle on which the installation is designed to operate is a combination of the Ward-Leonard system, with its ease of manipulation and certainty of speed control, with a flywheel equalizer interposed between the winding motors and the supply mains.

The advantage of the equalizer in this instance is shown by the fact that, whereas the peak load on the winding motors, when working on full duty, is 3,425 H.P. for each winder, the maximum demand on the Generating Plant is considerably less than half that figure. A further advantage obtained by the use of the flywheel system is that, in the event of the main supply failing, sufficient stored energy is available to complete a wind.

The winding drums are of the parallel type, 16 feet diameter and 13·5 feet wide, and when on final duty they will each be fitted with a balance rope of the same weight per fathom as the winding rope.

When the sinking of the pit shafts is completed, each winding engine will be required to work to the following conditions :—

Output of coal per hour .. 267 tons.
Depth of shaft .. .. 730 yards.
Nett weight of coal per lift 4·5 tons.
Number of lifts per hour .. 59·25
Time of each complete cycle 60·75 seconds.
Time for changing trucks 12·64 seconds.
Nett time for each lift .. 48·11 seconds.
Weight of each cage with suspension gear .. .. 5·75 tons.
Weight of each truck .. 5 cwts.

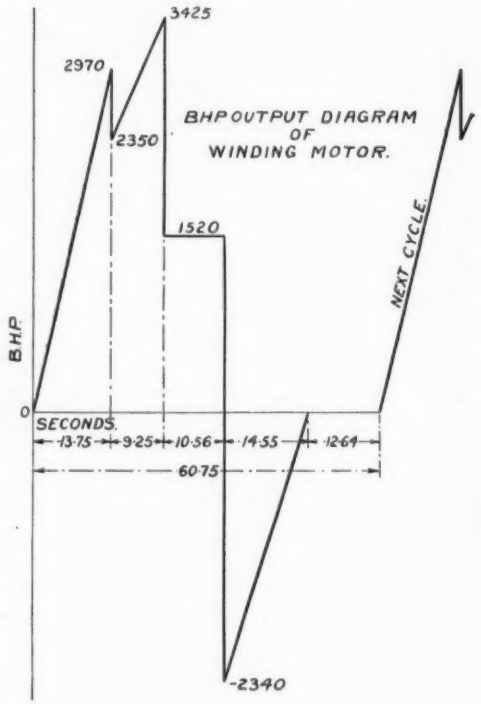


FIG. 1.

Number of trucks per cage 9
Weight of winding rope, per fathom .. .. 38 lbs.
Weight of balance rope, per fathom .. .. 38 lbs.
Diameter of winding drum 16 feet.
Maximum drum speed .. 86 R.P.M.
Maximum speed of winding 72·16 feet per second.

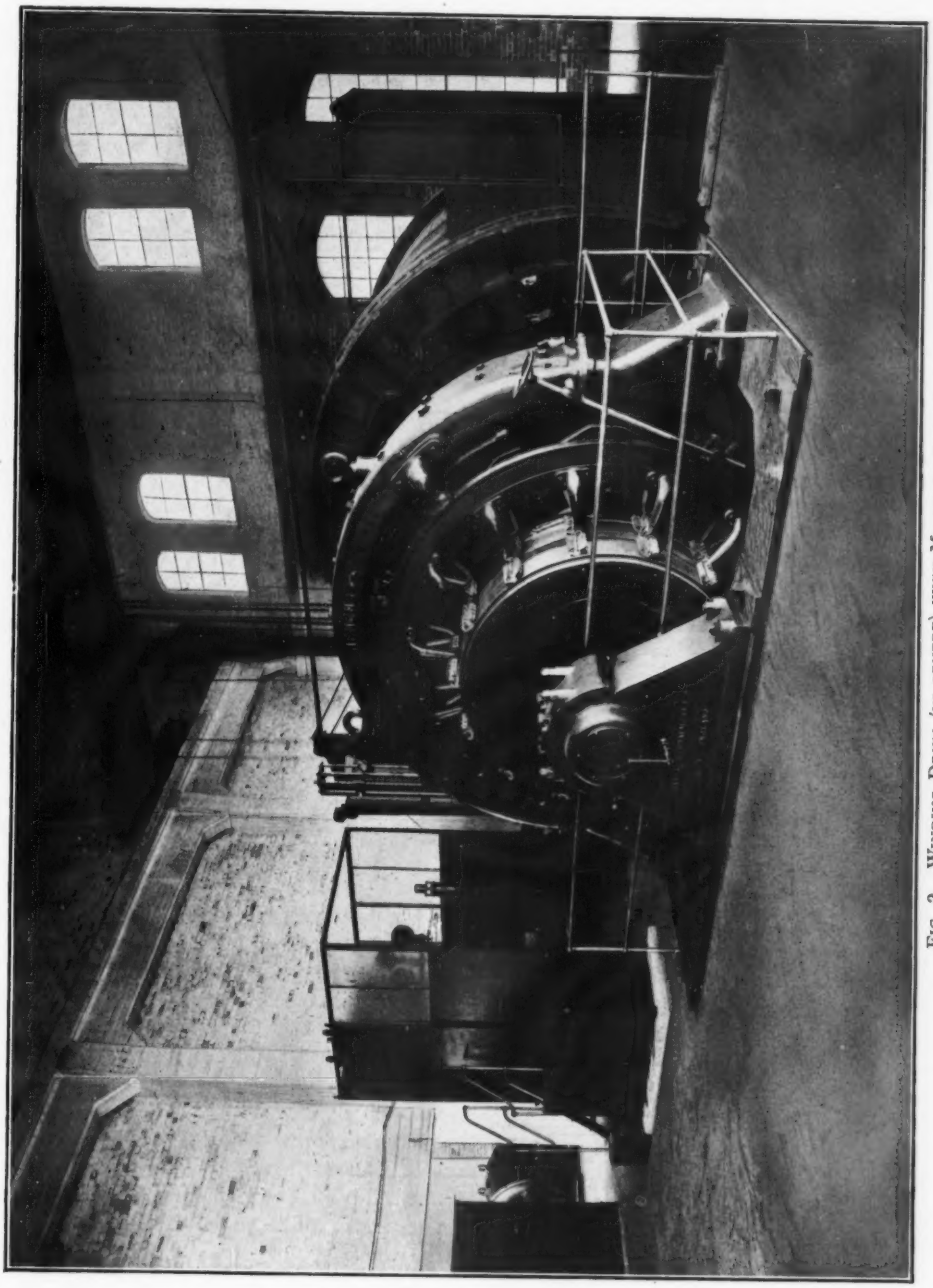


FIG. 2. WINDING DRUM (IN CENTRE) WITH MOTOR AT EACH END.

Taking the above conditions as a basis, it is calculated that the B.H.P. output for the winding motors at the various stages of the winding cycle will have approximately the values shown in Fig. 1.

For driving each winding drum there are two direct-current motors, each having a continuous rating of 1550 B.H.P. at 86 R.P.M., direct-coupled to the drum shaft, one at each end. Fig. 2 shows one of the drums with one motor in the foreground, while part of the second motor can be seen between the arms of the winding drum.

Each pair of winding motors is supplied with current from its own converter set, which consists of (1) two variable-voltage generators for the main supply to the winding motors (2) a generator for the excitation circuits, and (3) an induction motor for driving the set. The two converter sets are mounted in line, with two 27-ton flywheels in between, the flywheels being connected to each other and to each set by flexible clutch couplings, so that both units may be run as one set, or either unit independently with or without its flywheel. Each coupling is capable of transmitting 4,000 H.P. Fig. 3 is a view of one of the converter sets, showing at the distant end a portion of the flywheel of the second set; each of the above-mentioned components can be easily distinguished.

The induction motors are of the slipring type and are supplied directly from the 3-phase 3,300/3,000-volt, 50-cycle colliery mains. They run at a normal speed of 493 R.P.M., but are provided with automatic slip regulators in the rotor circuits by means of which resistance is inserted during the acceleration periods and the flywheels thus caused to give up some of their kinetic energy.

Each of the steel flywheels for the motor-generator sets has a diameter of 12 feet 3 inches and weighs 27 tons. The complete wheel is built up of two rings, forming the rim, clamped on each side of a central disc, the parts being interlocked by turned tongues and grooves in such a way as to relieve from centrifugal stresses the bolts which pass through the rings and disc.

As will be readily understood, the accurate balancing of such large flywheels is a matter of the utmost importance; the method adopted was one originated by the makers, in which the wheel mounted on its shaft is supported in bearings and floated on oil forced under the journals. The extent to which friction is eliminated by these means may be judged from the fact that after balancing these particular wheels, the weight of a penny ($\frac{1}{3}$ oz.) applied at the rim would start the wheel slowly rotating; this is believed to constitute a record for sensitive balancing.

The flywheel shaft bearings are of the self-aligning type, lubricated by forced feed under an oil pressure sufficient to lift the shaft. The bearing surfaces are not, therefore, in metallic contact, and the bearing friction is consequently exceedingly low.

For maintaining the necessary pressure there are oil pumps of the gear wheel type, driven from the flywheel shaft, and also separate auxiliary motor-driven pumps for use when starting up or in emergency. After passing through the bearings the oil enters an oil cooler situated in a tank formed in the flywheel bedplate, and thence again to the pumps, thus forming a closed system.

Powerful brakes are provided under the wheels for stopping them and they can also be employed to lift the wheels, in order to examine the bearings, etc.

At each end of the flywheel shafts is fitted a combined flexible coupling and clutch, designed in such a way as to permit of disconnection being effected, if necessary, whilst the set is running.

The alternating-current supply and the various direct-current excitation circuits are controlled from the switchboard shown in Fig. 4. There is, in addition, a changeover board arranged so as to give complete elasticity in the supply of any winding motor, or pair of

FIG. 3. ONE OF THE FLYWHEEL CONVERTER SETS.

motors, from any variable-voltage generator or pair of generators. The advantage of this arrangement is, that should one converter set be stopped for any reason, it would still be possible to keep both winders running. It is also possible to run both winders on light load from one converter set, without the flywheels, during periods when actual coal winding is not required, as for instance, during the night or week-ends.

be exceeded, while it also ensures that the speed of winding is gradually reduced towards the end of the wind, and the drum brakes applied, should the driver have failed to do so in time.

The depth indicator is also provided with a device for tripping the main brakes in the event of an overwind by either cage.

With the system of control used in this installation, any given position of the control lever corresponds to one particular speed, and

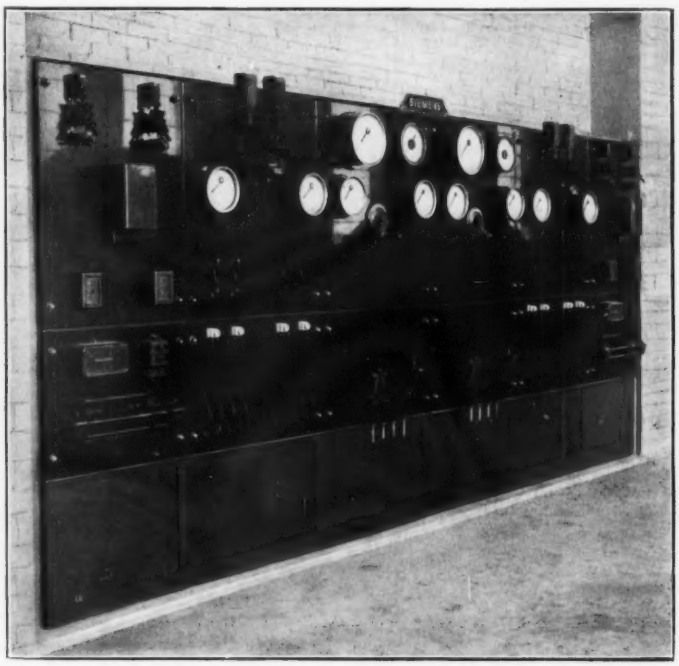


FIG. 4. MAIN SWITCHBOARD.

The speed and direction of rotation of the winding motor are controlled in the usual way by regulating and reversing the field current of the variable-voltage generators. The regulator is directly operated by the driver's control lever, the movement of which is in turn controlled by cams operated by the depth indicator. The interlocking is such that the driver cannot cause a pre-determined rate of acceleration to this holds good within very small limits, whatever the load, and whether the load is being raised or lowered. If the speed of the winding motor increases beyond the correct speed, as for example when lowering a load, electrical braking comes automatically into operation owing to the winding motor becoming a generator and returning energy to the converter set, thus assisting to speed up the flywheel again.

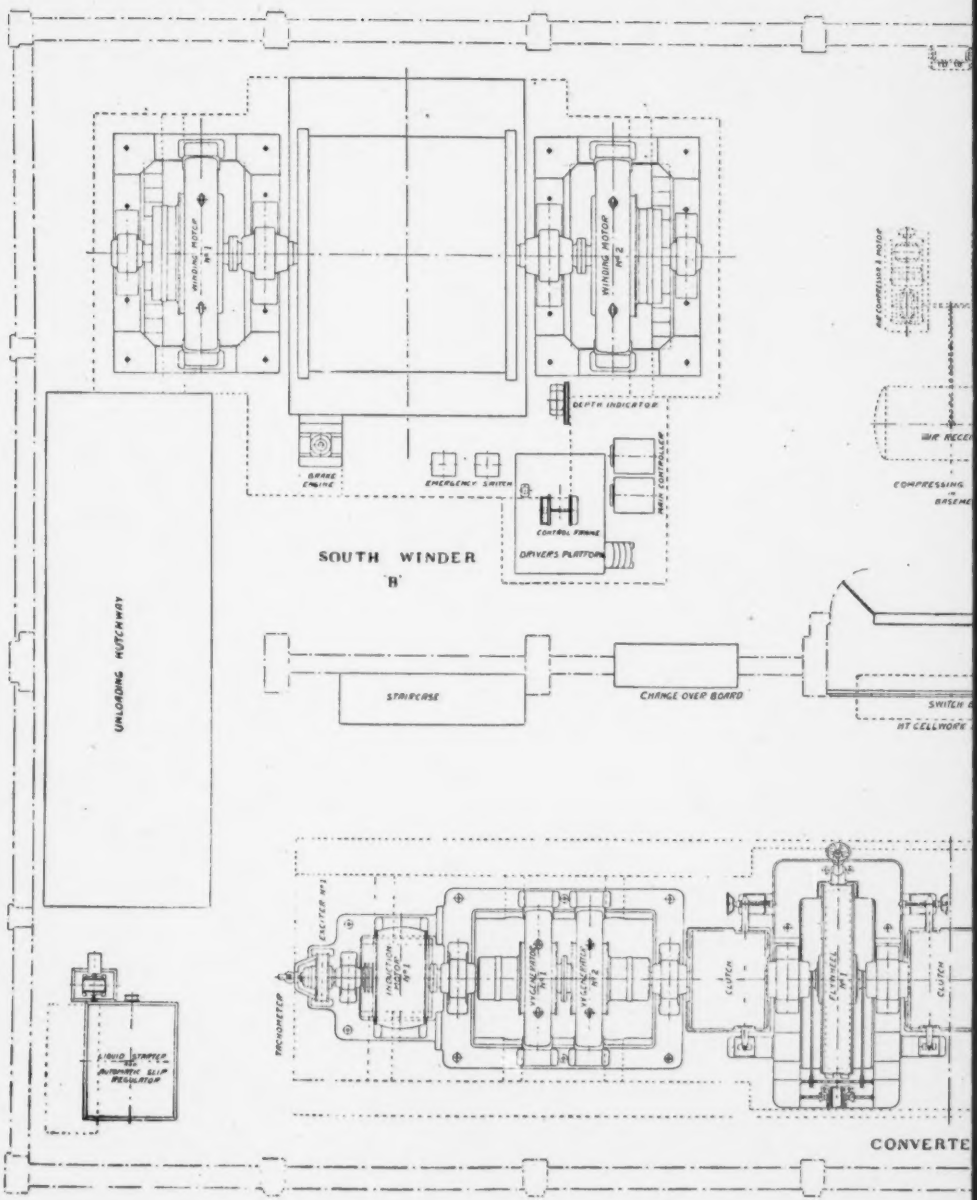


FIG.

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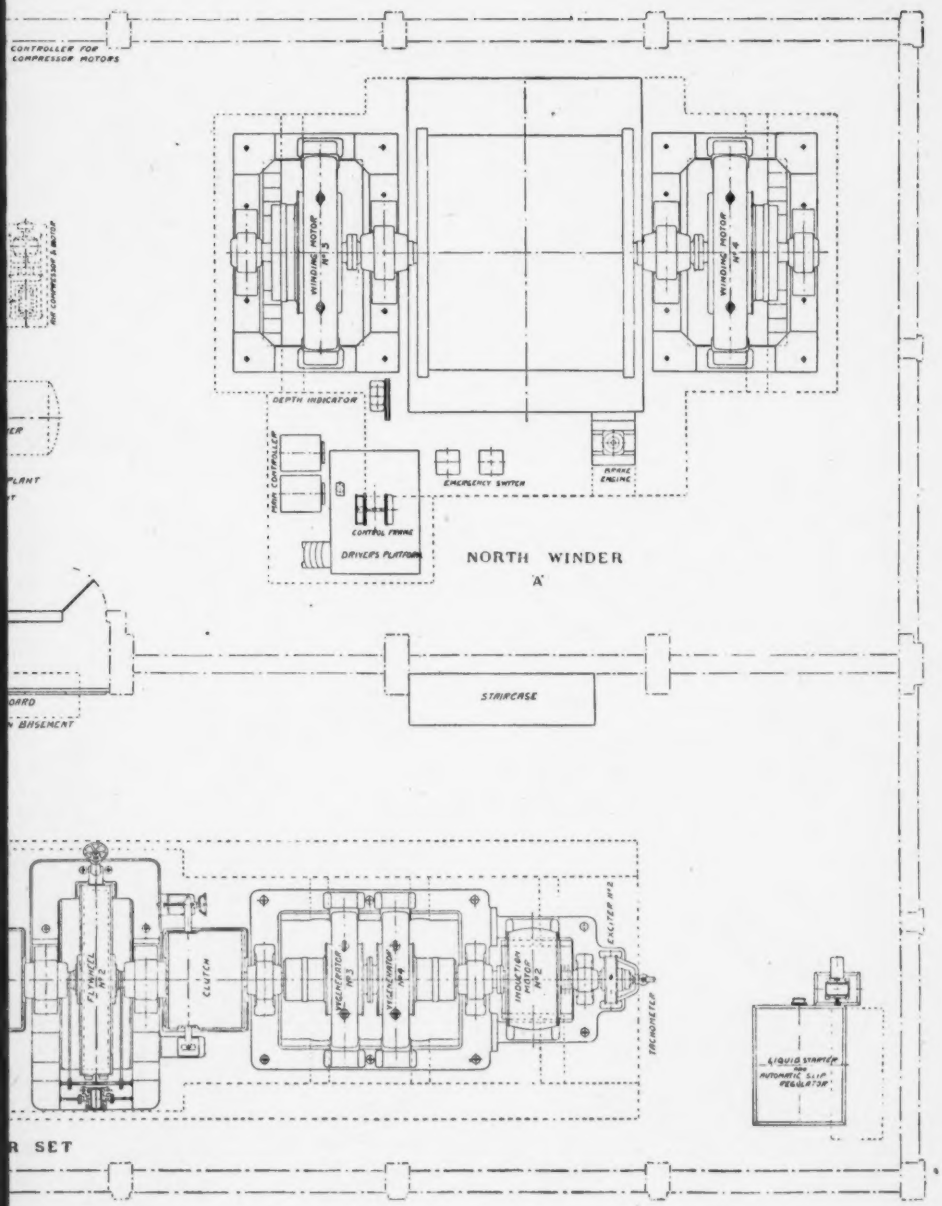
CONTROLLER FOR COMPRESSOR MOTORS
WINDING MOTOR No 5
WINDING MOTOR No 6
DEPTH INDICATOR
MAIN CONTROLLER
EMERGENCY SWITCH
BRAKE ENGINE
CONTROL FRAME
DRIVER'S PLATFORM
NORTH WINDER
A
STAIRCASE
BASEMENT
FLYWHEEL No 2
CLUTCH
EXCITER No 3
TACHOMETER
LIQUID STARTER FOR AUTOMATIC SLIP REGULATOR
R SET

For this reason, an overspeed apparatus is not provided on the winding engine itself, but the converter set is provided with a device which trips the main brakes in the event of its speed becoming excessive. This device, which consists of a speed indicator fitted with maximum and minimum contacts, may be seen at the end of the converter set in Fig. 3.

The energy given up by the rotating parts of the winder during the retardation period at the end of the wind is usefully absorbed in the converter set, in the manner described above, instead of being lost, as would be the case if the drum brakes were used ; at the same time the wear on the brake blocks is considerably reduced.

Devices are provided for tripping the brakes on the winding drum in the event of failure of the main supply or excitation circuits, failure of the winding motor field circuit, or excessive overload on the winding motor. They can also be tripped at any time by means of a hand lever mounted in the driver's control frame.

Each winding drum is carried between its own bearings, the drum shaft being extended at each end and provided with a half-coupling for bolting up to a similar half-coupling on each motor shaft, so that the whole line consisting of winding drum and two motors is carried in four bearings.

The main brakes are of the post type, applied by weights and raised by means of a " Whitmore " compressed-air engine, the compressed air being provided by an electrically-driven compressor situated in the basement. The same brake engine and gear are used for the emergency brakes, so that most of the parts required to act in emergencies are in frequent use, and their satisfactory working is thus under continuous observation.

Connected to each winder is a recording tachograph which records the duration and speed of every wind.

The power supply is derived from the Hulton Colliery Co.'s Generating Station, in which are installed two turbo-alternators, each of 1,500 K.W. and one turbo-alternator of 2,000 K.W. capacity, each set running at 3,000 R.P.M. These Generators were manufactured at the Siemens Works of The English Electric Company, and are driven by Richardsons-Westgarth Turbines.

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